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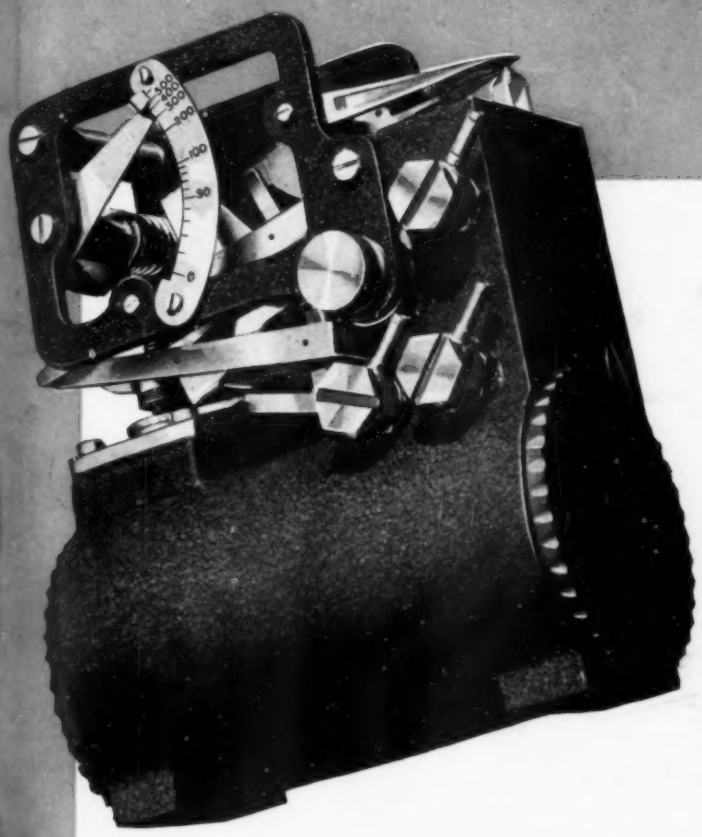

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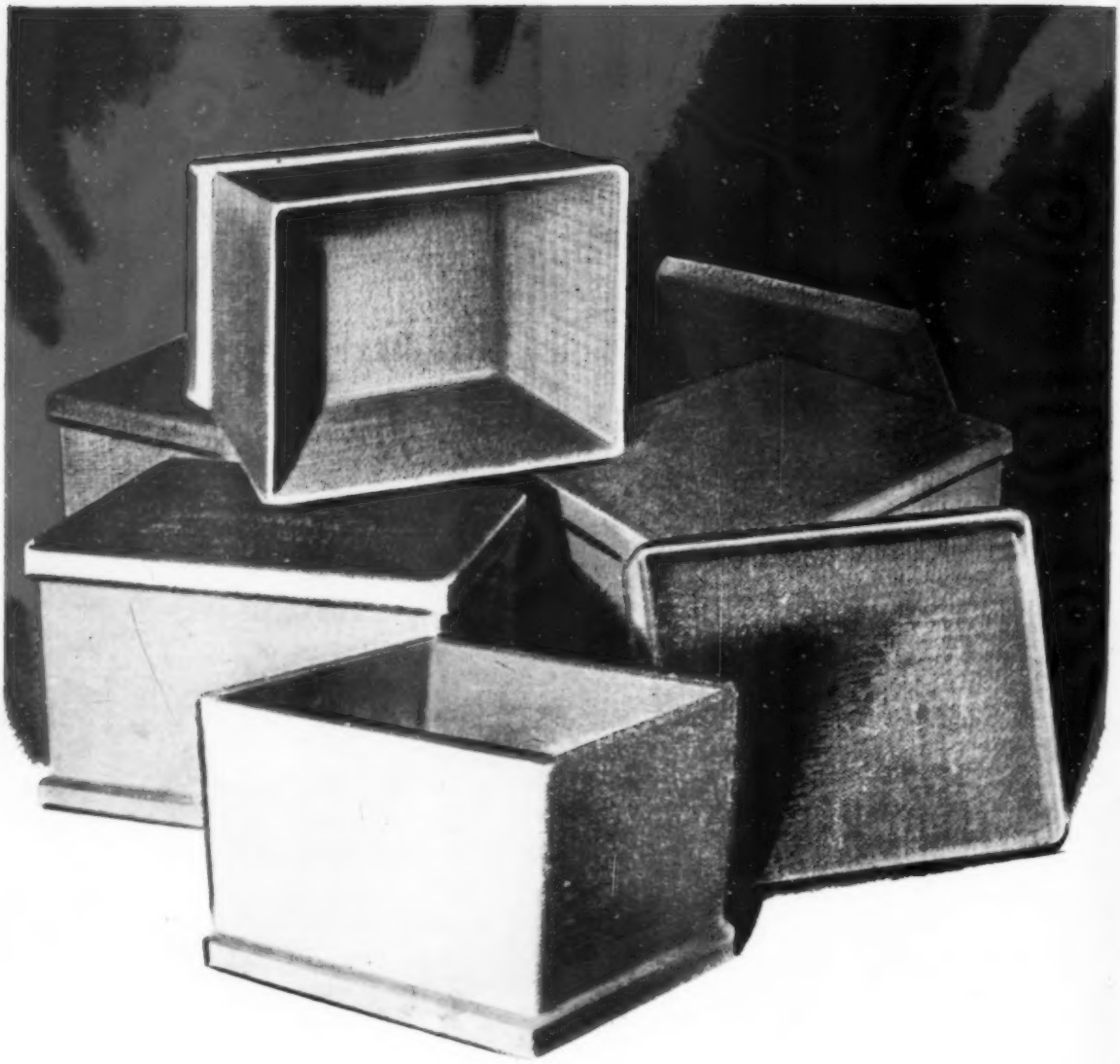

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(INCORPORATING THE METALLURGICAL ENGINEER)

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METALLURGIA

THE BRITISH JOURNAL OF METALS.

INCORPORATING "THE METALLURGICAL ENGINEER."

SEPTEMBER 1948 Vol. XXXVIII No. 227

Steel Allocations

ALTHOUGH the output of steel in Britain has reached an all-time peak level, with prospects of further production records before the end of the year, there is a growing concern among the managements of many of the country's most important works about the inadequacy of supplies. With an output of steel during the first half of this year at the rate of nearly 15½ million tons per annum, the steel industry is one of the few industries producing in excess of its target. Either the targets set for the various industries must have been insufficiently considered to effect a reasonable balance between production and consumption of steel or there is something seriously wrong with the distribution. Otherwise the steel in excess of the target, rightly allocated and consumed, would enable at least some other industries to exceed their targets. There is, however, little or no evidence that the additional tonnage of steel made available has been used to this end, and it would seem that, instead of lamenting the shortage of steel, an investigation should be made to find the cause of the discrepancy between production and consumption of the steel made available.

One of the most important of Britain's steel-consuming industries to complain of inadequate allocations is the shipbuilding and engineering industry. Managements of shipyards have frequently expressed their dissatisfaction with the supplies made available to them. Not only are the construction and the repair of vessels being delayed, but in some centres men are being discharged, and it is feared that, in the absence of better supplies of raw materials, there will be much unemployment in this industry during the months ahead. The Chancellor of the Exchequer's promise of a 5% increase in allocation is described by shipyard managements as "a drop in the bucket" and complaint is made that the Government's control of supplies is less efficient that it ought to be.

The shipbuilding and marine engineering industry is not by any means alone in making this complaint, it is becoming increasingly general among steel-consuming industries, but we have purposely referred to this industry because we regard it as among the most important of this country's industries. As the premier maritime nation of the world, we cannot afford to neglect our shipping. Not only must we hasten to replace the losses sustained during the war and keep those available in a serviceable condition, but we must strive to maintain our enviable reputation for shipbuilding, in respect both of design and durability. Faster transport between overseas countries is needed and nothing should interfere with the gradual replacement of slower vessels. Apart from our own needs, however, the reputation of our shipyards for reliable work at competitive cost ensures substantial orders for vessels from foreign countries and from the Dominions. Certainly a greater proportion of the steel produced in excess of the target figure could be diverted to shipbuilding with profit to the nation as a whole.

Attention is called to the fact that output of the iron and steel industry is well ahead of schedule by the Iron and Steel Federation which recently hinted that the day was not far distant when, in view of the much higher output, the allocation scheme would be dispensed with. It is noteworthy that the Government has announced a special purchase of 100,000 tons of steel from Belgium and Luxembourg, which will be additional to the quantities obtained from these countries under current trade agreements, thus further steel will be available for allocation.

There is another aspect of inadequate allocations of steel that is causing managements much concern: the fear that the absence of better supplies will cause unemployment has already manifested itself among workers who have appreciated the signs and are pursuing a "go-slow" policy. Indeed, it is probable that there is not a single job where the psychological effect of the expectation of a shortage of raw material has not produced a slowing down of the pace in order to keep the work in line with deliveries. In Britain's present economic position, especially when every effort is being made to live down the habit of restrictive outlook, nothing could be worse. The remedy is not in telling men to work harder but in organising and allocating supplies of raw materials so that they *can* work harder. It is not as though there is a scarcity of work to be done, but if deliveries of work in hand cannot be effected as promised, due to shortage or faulty distribution of materials, then scarcity of work will ultimately result, with all its consequences.

This question of raw material allocations must be carefully examined to make sure, as far as is humanly possible, that supplies made available are used to maintain a steady recovery in Britain's industrial production. Her economy has not yet had time to build up adequate stocks at all stages of production, and it does not help towards a solution if some industries carry heavy stocks while others have to operate on a hand-to-mouth policy. Complaints about inadequate supplies cannot be neglected; there is too much at stake, since they reduce the nation's capacity to recover and among other reactions must ultimately interfere with the maintenance of full employment, stable wages, and the success of the new social services.

What steps should be taken to ensure a more equitable distribution of essential raw materials is a problem not easily solved, but in regard to steel the feeling gains strength that the Government does not know where supplies are going. Should the proposed Anglo-American advisory council be set up we shall probably learn that in the United States there is a steel consumption analysis as well as figures giving production. Such an analysis in this country would certainly assist in tracing unused stocks and incidently would help the Government and the industries concerned to plan with greater accuracy.

British Aircraft Display

THE ninth Flying Display and Exhibition to be staged by the Society of British Aircraft Constructors, Ltd., held on September 7-12 inclusive, proved an outstanding success. Not only was it by far the biggest in the series but the large number of representatives from foreign countries indicated the great interest being shown in the progress of designers and constructors of British aircraft. The number of aircraft on view exceeded expectations, nearly 70 of the latest civil and military aircraft, including new and experimental types, took part in the flying programme, the majority of which were on view for the first time, and it was not surprising to hear foreign experts express their opinion of the display as the best in the world.

For the first time this annual show was open to the general public. This was made possible through the co-operation of the Ministry of Supply, by staging the display and exhibition at the aerodrome of the Royal Aircraft Establishment at Farnborough. Thus the Society was able to fulfil its long-expressed intention of admitting the public to this unrivalled air event, since this aerodrome provides the facilities and amenities necessary for about seventy thousand spectators.

Among the many new types flown were two Hawker turbo-jet aircraft, a carrier and a land-based version of the single-engined fighter. Some disappointment was felt that the new Gloster turbo-jet fighter was not flown, but considerable interest was shown in other turbine engined military aircraft, which included the Vickers Supermarine Attacker, the Gloster Meteor, the de Havilland Vampire and High Altitude Vampire, and the Saunders Roe twin-engined flying boat fighter.

Civil aircraft was well represented and included the Vickers-Armstrong Nene-engined Viking and the same company's prototype Viscount, the Handley Page Hermes IV, Airspeed Ambassador, Avro Tudor IV and VIII, the latter making a triumphal appearance over the aerodrome, and the Percival Prince prototype. Helicopters were represented by the Bristol prototype, the Fairey Gyrodine and a Sikorsky machine demonstrated by Westland Aircraft, Ltd. Among trainer aircraft much interest was shown in the Avro Athena, the Boulton Paul Balliol, and the Percival Prince.

The aerial activities were certainly given a fitting start by the arrival of the Tudor VIII, and it was encouraging to hear Sir Roy Dobson, C.B.E., President of the Society, point out at the official opening luncheon, that the lead in jet turbines established during the war had not been lost, he reminded his audience that what was displayed at Farnborough formed only a part of the work so far achieved. Behind the scenes, he said, the pace of development was accelerating and there was good reason for confidence that Britain would remain in front.

Of the aircraft displayed some thirty-one were new to this exhibition and there were sixteen different types of gas-turbine power units. The much discussed Tudor, the Tudor VIII, driven by four jet engines, gave a good account of itself. But probably the most astounding feat during the course of the exhibition was that performed by the De Havilland 108 in which the test pilot John Derry achieved the speed of sound. This machine was later displayed before the general public, but at a respectful distance. As the industry exported aviation equipment to the value of £24 million during 1947, it would be interesting to know the value of orders placed as a result of this display.

While the flying display undoubtedly captured the imagination of the visitors and created considerable enthusiasm, the static exhibition, which was represented by about 200 firms, gave very convincing evidence of the foundation on which British aircraft achievement is built. Practically every phase of the industry was represented, apart from the builders of complete aircraft. In addition to complete engines there were production equipment, components, materials, and many instruments, pumps and other ancillary items and equipment. It was particularly interesting to note the progress made in the production of light metal castings, which included pressure die-castings as well as gravity die- and sand-castings. Small steel castings also attracted considerable attention, while many of the special alloys developed for turbine engines were shown. There was much in evidence to support the claim that in many aspects of the gas turbine field Britain continues to lead the world.

National Foundry College

THE new session of the National Foundry College will begin at the Technical College, Wolverhampton, on September 27th, 1948. Intending applicants should apply to the Head of the College, Mr. J. Bamford, B.Sc.

Candidates with suitable practical experience and technical knowledge will be admitted direct to this full-time Diploma Course, which will end in July, 1949. A minimum of one year's practical experience is required in the founding industry, together with an appropriate university degree, or Higher National Certificate, coupled in the case of the latter with a record of additional study, or special responsibility.

Experience has shown that some candidates require more preparation, particularly where the major technical colleges are not readily accessible to them. For these a preliminary course of six months' duration, to be called Part I of the Diploma Course, will be arranged to begin in January, 1949. The present Diploma Course will become Part II, and the intervening period between the end of Part I in June, 1949, and the beginning of Part II in the following September, can be spent in acquiring foundry experience. Normally, Part I and Part II will in future begin at the same time in September of each year, and run concurrently, thus allowing to those students who take both parts an interval of six months between Part I and the beginning of the succeeding Part II to be spent in acquiring foundry experience which will count towards the practical experience required for admission to Part II. However, it will not be essential for students to take Part II immediately after Part I.

It is anticipated that candidates whose technical knowledge in the past has not been adequate to admit them to Part II will be able to equip themselves sufficiently through Part I, but those with suitable qualifications will be admitted direct to Part II. Candidates who are in doubt as to which part of the course their experience and qualifications entitle them to register are advised to apply to the Head of the College. Every application will be treated on its merits and the most suitable course recommended. As previously, it is anticipated that many candidates will be sponsored by their employers in all branches of the industry. The fee for Part I is £40 and for Part II is £60. The Board of Governors may remit fees for all those candidates whose employers belong to a trade association giving financial and other support to the College.

A Rotating-Load, Elevated Temperature Fatigue-Testing Machine*

By J. McKeown, D.Sc., M.I.Mech.E., F.I.M., and L. H. Back, B.Sc.

(*Communication from the British Non-Ferrous Metals Research Association.*)

This report describes in detail a new form of high-temperature fatigue-testing machine which has been designed and constructed in the laboratories of the British Non-Ferrous Metals Research Association. The principle of operation is a modification of the normal Wöhler test in which a rotating cantilever specimen is subject to a constant bending moment, the material at any point of the specimen being subjected to equal and opposite stresses during each cycle. In the rotating load fatigue machine one end of the cantilever specimen is held stationary, and a constant value rotating bending moment applied by means of a rotating out-of-balance mass at the other end. A stationary specimen permits accurate measurement of temperature to be made by a thermocouple in intimate contact with the section at maximum stress.

Introduction

DURING the war, the need arose for data on the fatigue properties at elevated temperatures, of some light alloys intended for use in aeroplane and engine parts, and the Association was asked to develop a machine of simple design suitable for high-temperature fatigue testing. In view of the mass of data on the fatigue properties at room temperature which had already been obtained on Wöhler machines, it was considered desirable that the new machine should operate on a similar principle, so that results would be directly comparable.

An account of a machine designed to operate on such a principle, and suitable for use at temperatures up to 300° C. was made available to members of the B.N.F.M.R.A. in November, 1945. The present paper describes further developments which have resulted in a machine suitable for use at temperatures up to at least 700° C.

In machines of the Wöhler type, the specimen is subjected to simple or uniform bending whilst rotating at a speed of 2,000–3,000 r.p.m. While there is no difficulty in heating the specimen by a surrounding electric furnace, the accurate measurement of its temperature is difficult.

Measurement of the air temperature close to the specimen is unsatisfactory, as a very steep temperature gradient exists at this point. Calibration of the specimen temperature against the air temperature close to its surface can only be carried out when the specimen is stationary, and it is certain that such a calibration would not hold for the conditions obtaining when the specimen is rotating at speed and the layer of air in contact with its surface is disturbed by the proximity of the measuring thermocouple.

Attempts have been made in some laboratories to measure the specimen temperature by means of a thermocouple in contact and rotating with the specimen, the small generated e.m.f. being led via slip rings and brushes to the millivoltmeter. There are two difficulties encountered in such a procedure—namely, the pick up of vagrant thermal e.m.f.'s due to subsidiary hot junctions at brush gear, etc., and contact trouble at the brushes. The use of silver/silver-carbon for slip rings and brushes affords a limited measure of success, but the attendant experimental difficulties are considerable.

After due consideration it was decided that a satisfactory solution of this problem could only be obtained when the specimen was stationary. This meant that, in applying the simple Wöhler principle, the load and not the specimen would have to rotate.

Description of Machine

An assembly drawing of the machine is shown in Fig. 1. The specimen S, having its section of maximum bending stress at C, is clamped at one end to the main support A, being held by four heat-insulated, hardened steel grips B. The other end of the specimen is a push fit in an aluminium-bronze sleeve I, which is itself a force fit in a sindanyo sleeve H. The sleeve I is oxidised, the oxide film together with the heat-insulating properties of the sindanyo minimizing the heat flow from the specimen to the deep-grooved ball-bearing K, which is a force fit on the sleeve H. The end of the specimen is screwed, allowing the whole assembly H, I, K, to be drawn up against the shoulder of the specimen by means of a nut and a sindanyo washer L. The assembly is thus prevented from rotating, and the bearing heat-insulated from the specimen.

The bearing is retained in the housing J by the cover plate D. The two gimball pins P are force fits and pinned in the bearing housing J, and carry an outer ring O. At right angles to the centre line of the pins, this outer ring carries a radial arm R, on which is mounted a small mass W, whose position can be varied to give any degree of effective out-of-balance mass.

On rotating the housing J, the centrifugal force due to the effective out-of-balance mass is transmitted to the specimen through the pins and the bearing, and deflects the specimen in a direction at right angles to the centre line of the pins. The rotating head is driven through a flexible rubber coupling T, which allows deflection of the specimen to take place in the direction of the out-of-balance force.

If, then W_e = total effective out-of-balance mass.

r = radius of rotation of this mass.

and ω = angular velocity of rotating-head.

Then $F = \dfrac{W_e r \omega^2}{g}$ where F is the rotating load.

* *B.N.F.M.R.A.* Research Report. R.R.A. 792P.

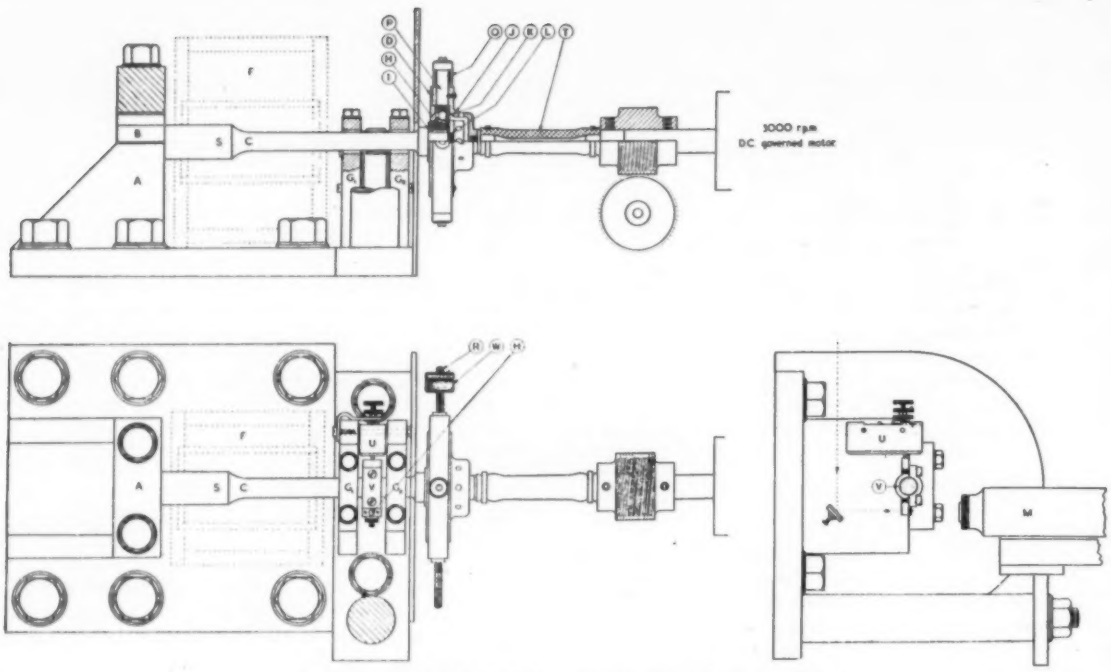


Fig. 1.—Rotating-load fatigue-testing machine assembly.

We see that F is determined by three independent variables, or for the case of constant speed testing, by W_e and r. Hence, the magnitude of the rotating load may be adjusted to give any required bending stress at the section C by altering the position of the mass W and, if necessary, by changing its magnitude.

The deflection of the specimen under test is observed by passing a beam of light through a small hole at h into the microscope M. The hole, h, is made in a piece of thin foil which is rigidly attached to the specimen by the clamp V. This small hole is seen in the microscope as an illuminated circle when the machine is stationary and as an illuminated band, of length twice the deflection plus the diameter of the circle, when the machine is running. The measuring head of a Vicker's hardness tester is used for determining the length of this band, and the use of objectives of various focal lengths allows the measurement of deflections obtained with materials of very different mechanical properties without sacrifice of sensitivity.

On fracture of the specimen, the deflection of the clamp V is sufficient to trip the micro-switch U. This micro-switch operates relays in both motor and furnace control circuits and switches off the motor and furnace. Provision is made for adjusting the position of the micro-switch to accommodate any deflection.

A small tension is applied to the specimen through the rubber coupling T to separate the fractured ends of the specimen immediately failure occurs. Guards G_1 and G_2 limit the throw of the rotating assembly, whilst the motor is running down. The principle of regenerative braking is used to bring the motor to rest in about 2–3 seconds.

The furnace F is of tubular design, consisting of two end plates of asbestolite, a silica-tube former and metal sheet surround, the whole being lagged with asbestos wool. Control of the furnace over the range 20°–700° C. is accomplished by means of a Sunvic energy regulator and a tapped transformer. Fig. 2 illustrates the wide range of temperature obtained by these means. The electrical control circuits for the motor and furnace are given in Fig. 3. Up to the present the machines have been located, as a matter of convenience, in a room, the temperature of which does not vary by more than ± 2° C. and the temperature control of the specimen has been obtained by the use of the energy regulator alone. Under these particular conditions the specimen temperature remains constant throughout a test to ± 1%. If the machines are located where a greater

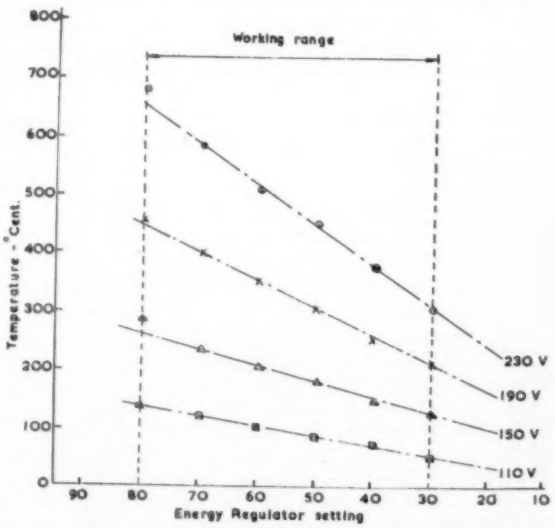


Fig. 2.—Furnace control by means of energy regulator and tapped transformer.

variation of ambient temperature occurs, it is necessary to apply some form of thermostatic control to the furnace.

Specimen temperature is measured by means of a thermocouple, with a flattened weld-bead, strapped by asbestos tape in direct metallic contact with the specimen at the Section C. The couple is connected to a Cambridge recorder and a continuous record of the temperature is taken throughout the duration of the test. The machine is driven by a $\frac{1}{2}$ h.p. 3,000 r.p.m. D.C. governor controlled motor, a note on which is given in the Appendix. Fig. 4 is a photograph illustrating the general layout of the machine.

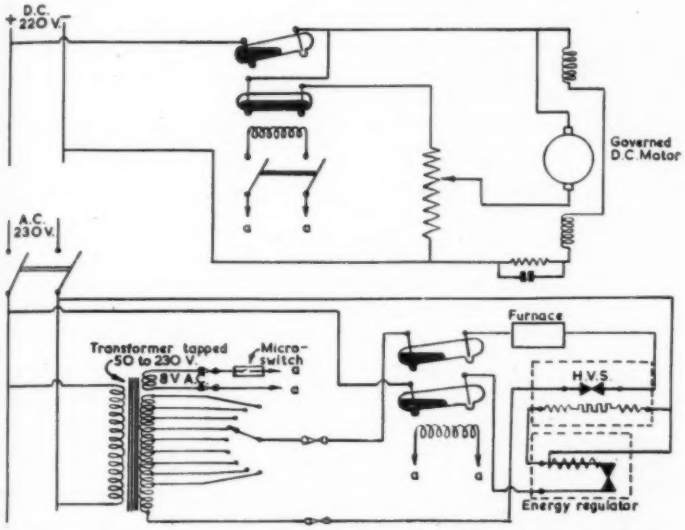


Fig. 3.—Circuit diagram of rotating-load fatigue-testing machine.

Specimen Design

The specimen dimensions are dictated by temperature and resonance considerations.

In an early stage of its development the machine was fitted with a self-aligning ball race, and the bearing-housing rigidly connected to a torque rod. When attempts were made to use the machine for testing above 300° C. it was found that, because of expansion of the inner race, the bearing became too tight to allow the necessary alignment to take place. In the present design the specimen has been lengthened in order to keep the bearing temperature as low as possible, and the necessary alignment of the outer ring is provided by trunnion pins remote from the specimen as described above. The overall length of the specimen now employed is $9\frac{3}{16}$ in.

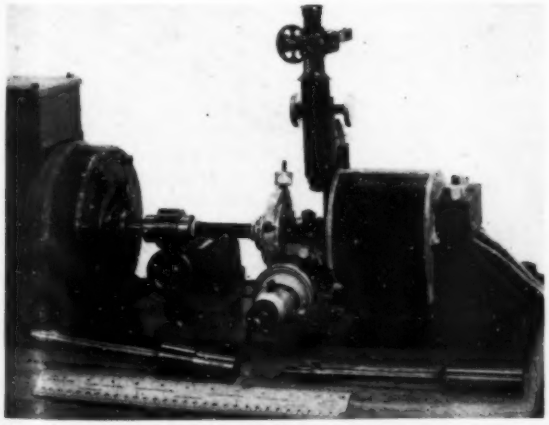
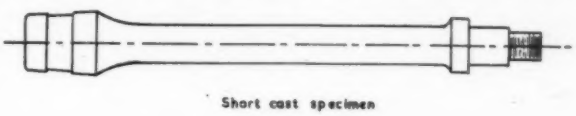
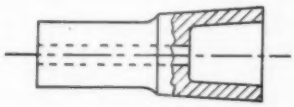


Fig. 4.—Side view of machine showing two types of specimen.



Short cast specimen



Extension piece

Fig. 5.—Design of extension piece for use with specimens of limited length.

and the effective moment arm is fixed at 5 in., which locates the section of maximum bending stress in the middle of the furnace.

With all Wöhler type machines, there is the possibility during starting of running through critical speeds and so over-stressing the specimen. The primary critical motor speed will be that corresponding to the fundamental frequency of the cantilever specimen and its end load, and is given approximately by the expression—

$$n = \frac{30}{\pi}\sqrt{\frac{3EIg}{\left(m + \frac{33}{140}\mu L\right)L^3}} \text{ cycles/minute.}$$

where

- m is the end load—i.e., in the case of the rotating load machine, the wt. of the rotating assembly.
- μ is the wt./unit length of effective moment arm.
- L is the length of the effective moment arm.
- E is the elastic modulus of the specimen material.
- I the moment of inertia of the specimen section about a diameter.

Considerable magnification of the normal deflection will occur at this natural frequency. It is, therefore, necessary to employ a specimen which is either stiff enough to ensure this critical speed being greater than the testing speed of 3,000 r.p.m. or sufficiently flexible to reduce the critical speed to a very low value, thereby avoiding severe stress magnification when passing through it.

For example, the primary critical speed for a light alloy specimen, 0·4 in. diameter, at 20° C., is approximately 3,000 r.p.m. It has been found that a 0·5 in. diameter specimen is sufficiently stiff to ensure the critical speed remaining greater than 3,000 r.p.m. at elevated temperatures up to 300° C. The convenient dimensions for light alloy specimens are thus, 5 in. moment arm, and 0·5 in. diameter at the section of maximum bending stress.

Specimens of cast material are most conveniently machined from standard D.T.D. test bars, but these, while giving a sound casting, limit the overall length to about 6 in. To overcome this limitation an extension piece was designed and made as illustrated in Fig. 5. It will be seen that the specimen is joined to the extension piece by male and female tapers, the necessary clamping force being provided by the differential expansion of the specimen and the heat-resisting steel extension-piece at elevated temperatures. For room-temperature testing the specimen is shrunk into the extension piece. Cast light-alloys have been successfully tested by this means

Calibration

When a test is to be carried out on this machine the stress-strain or more accurately the load-deflection curve for the specimen is first obtained. This curve enables the deflection corresponding to a given bending stress to be determined and the magnitude of the out-of-balance mass can be adjusted to produce this deflection and hence the required stress.

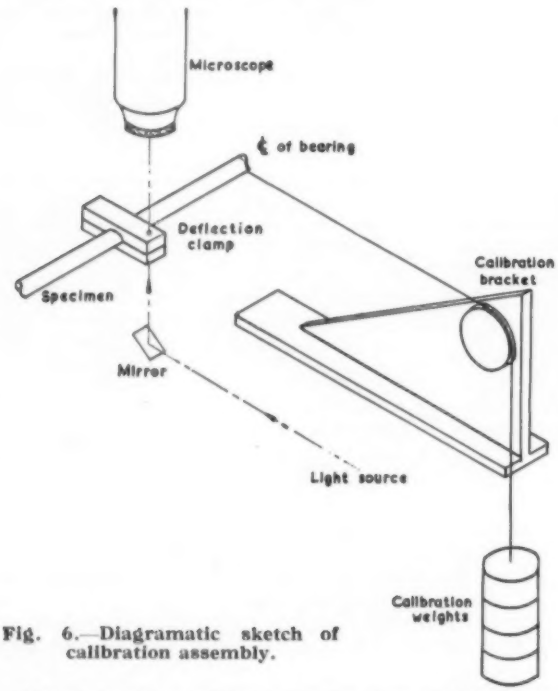


Fig. 6.—Diagramatic sketch of calibration assembly.

When the shape of the stress-strain or load-deflection curve is affected by rate of stressing, as is most likely to happen at elevated temperatures, it is necessary to determine the curve at a rate of stressing the same as that occurring in the fatigue test. Creep occurring during a calibration at a slow rate of stressing, referred to as a static calibration, may give a non-linear stress-strain relationship, whereas if time for creep to occur is not available because of the high rate of stressing—i.e., in a dynamic calibration, the relationship may be linear up to much higher stresses. A dynamic calibration method has been developed which enables the stress-strain relationship of a specimen at the testing temperature to be determined at the same high rate of stressing as occurs in the fatigue test. This method, described in detail below, consists of the application through the rotating

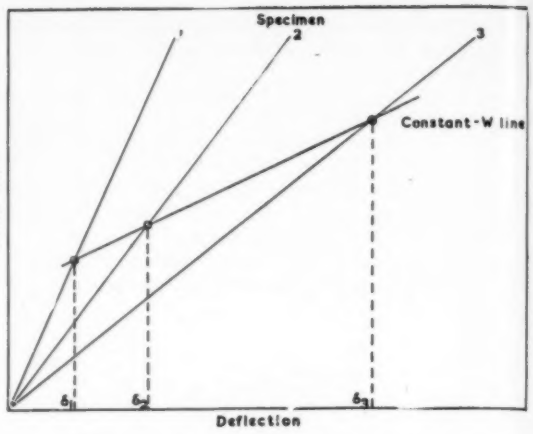


Fig. 7.—Stiffness lines of calibrating specimens and method of plotting Constant-W lines.

head of forces of known magnitude and the observation of the resulting deflections of the specimen.

A set of three standard mild steel specimens of diameters 0·450, 0·380, and 0·335 in., are calibrated statically in the machine at room temperature, for stresses not exceeding the elastic limit. With the machine uncoupled from the motor, forces are applied at the centre line of the ball-race by means of a bracket (Fig. 6) which ensures application of the force at right angles to the axis of the specimen and in a horizontal plane, and the corresponding deflections of the specimen are measured at the clamp V with the microscope and measuring head. When the load-deflection relationship for each specimen is plotted, three straight (elastic) lines of different slopes are obtained (Fig. 7). These may be referred to as stiffness lines.

The static calibration gear is now removed and the machine coupled to the motor. A series of small weights is then screwed in turn on to the stud R and against a

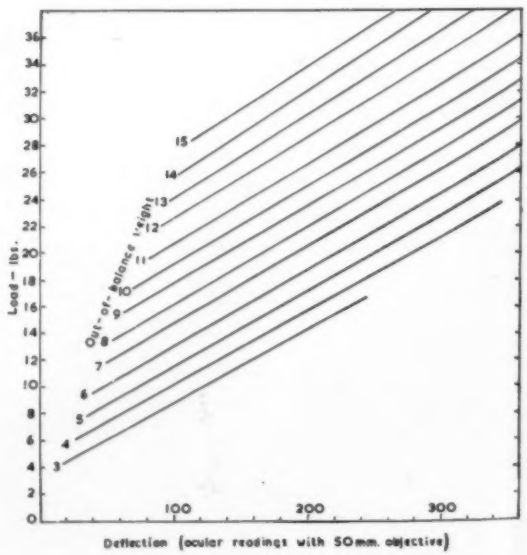


Fig. 8.—Constant-W lines for use with long specimen.

shoulder on the stud. The deflections produced by each weight, at the running speed of 3,000 r.p.m., with any one of the calibration specimens is determined. The force produced by each weight is thus obtained as the ordinate of the point of intersection of this deflection and the stiffness line of the specimen. The procedure is repeated for each of the three calibration specimens, and thus for any one of the small weights a series of points is obtained which lie on a straight line as shown in Fig. 7. It will be seen that as the stiffness of the calibration specimen is reduced the constant small weight produces an increasing bending force. The constant W-lines obtained in one machine using a series of thirteen weights, ranging from 0·008–0·036 lb. in approximately equal increments, are shown in Fig. 8.

The determination of these W-lines comprises the initial calibration of the machine, and, subject to periodic checking, they are used for all subsequent testing in the machine.

The widest practicable range of stiffness that can be accommodated is covered by the W-lines of Fig. 8 and test specimens are designed to have stiffnesses somewhere within this range.

It may be noted here that the assumption is made that in the elastic range of a material, in this case mild steel at room temperature, the strain is unaffected by the rate of application of the stress, in other words Young's Modulus is independent of rate of stressing. It is considered that this assumption is legitimate and one which can be extended to include any other material at any temperature where the initial portion of the stress-strain curve obeys Hooke's Law. Further reference will be made to this point later.

Calibration of the test specimen is carried out as follows. After the specimen has been held at the testing temperature for the predetermined soaking period, the machine is started with no out-of-balance mass and run while the temperature is again stabilised at the test value. It has been found that rotation reduces the temperature of the bearing and so, as the temperature gradient in the specimen is altered, the temperature at the critical section may be changed slightly. When a steady temperature has been reached the motor is momentarily stopped, one of the series of calibrating weights screwed on to the stud *R* and against the shoulder and the motor restarted. The deflection due to the out-of-balance force is noted, and in Fig. 8 the conditions will be represented by the intersection of the deflection ordinate and the appropriate W-line, thus determining the magnitude of the rotating force. By repeating this procedure with other calibrating weights the dynamic load-deflection relationship of the specimen is obtained. Now the deflection corresponding to any desired bending force can be deduced from it. The out-of-balance force is then adjusted by means of the small weights carried on stud *R*, the motor being stopped momentarily while adjustment is made, until the deflection corresponding to the required bending stress is obtained.

The differences that may be obtained between static and dynamic calibrations at elevated temperatures are illustrated by the curves shown in Fig. 9. These were obtained at 500° C. using a 0·4 in. diameter specimen of wrought aluminium bronze to D.T.D. 197A. This material which contains 8–11% aluminium, 4–6% nickel, and 4–6% iron is thought to be structurally stable at this temperature. The specimen was held at the test temperature for one hour before the calibrations were made. Firstly, the static calibration curve (*a*) was obtained up to a nominal bending stress of 10·5 tons/sq. in., and it will be observed that there is no proportionality of load to deflection, the line being curved right from the origin. Next the dynamic calibration curve (*b*) was obtained up to a bending stress of 11·5 tons/sq. in. The curve shows proportionality of load to deflection up to this stress and indicates clearly the effect of rate of loading on the stress-strain relationship. A second static calibration curve (*c*) was then obtained and found to differ only slightly from the first static calibration, and as before to be curved from the origin.

As stated earlier, in the actual fatigue test, the relationship which must be used is the dynamic one, and it is from this that bending stresses used in the test are determined. The dynamic and static room temperature calibrations of the same specimen are included for interest. They show that at room temperature, where the specimen is elastic within the calibration range and creep does not occur, the static and dynamic calibrations are identical.

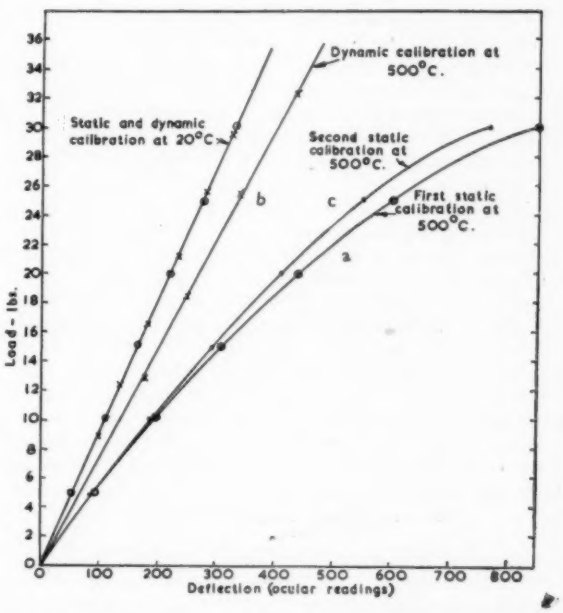


Fig. 9.—Comparison of static and dynamic calibrations of an aluminium-bronze specimen at 20°C. and at 500° C.

A second set of standard calibrating bars of mild steel are used for calibrating the machine for use with the short specimen and extension piece described in the foregoing section. These bars are machined to fit the extension piece shown in Fig. 5, and again have diameters of 0·450, 0·380, and 0·335 in.

In the next section the results of tests made on two light alloys, D.T.D. 424 and B.S.S. 2L33 in the temperature range 20°–300° C. are discussed. When these tests were made the dynamic method of calibration had not been developed and the stress-strain relationship for a specimen was determined from the elastic-line, produced where necessary, obtained in a static calibration. Subsequent to the development of the dynamic method of calibration a series of tests was carried out on specimens of the light alloys at each of the test temperatures. In

these tests the results of static and dynamic calibrations were compared, and it was clearly shown that while the dynamic limit of proportionality was higher than the static limit there was no difference within the limits of experimental error in the value of the elastic modulus in the two calibrations. Thus in the D.T.D. 424 specimen tested at 300° C. after 24 hours soaking period the ratio of the slopes of the dynamic and static elastic lines was 1·013, this showing that the possible error arising from the use of a static instead of a dynamic calibration was of the order of 1% in the stress. In the case of the 2L33 specimen tested at 300° C. the ratio of the slopes was 1·030. In the static calibrations, since the limit of proportionality was low in both specimens, it was more difficult to arrive at a true slope for the modulus line. On the other hand as the limit of proportionality was much higher under dynamic calibration conditions a more accurate value for slope could be obtained. Hence, it is considered that even in the case of materials which show a small range of proportionality of stress and strain under static conditions at the test temperature, the dynamic method of calibration is to be preferred.

Another point which may be noted at this stage is that some difference in temperature gradient along the flexed length of the specimen exists with the machine at rest and when running, even when the temperature at the critical section is the same in the two cases. Such differences in temperature gradient will affect the average value of the elastic modulus for the specimen and result in elastic lines of different slopes being obtained in static and in dynamic calibrations. Since, of course, the fatigue test is run under dynamic stressing conditions this gives an additional reason for preferring the dynamic to the static method of calibration.

The dynamic calibrations carried out on the light-alloy specimens also showed that the endurance limits obtained in the fatigue tests on these materials were not higher at each temperature than the dynamic limit of proportionality at that temperature. This is considered as an important finding as it indicates that the use of a formula based on elastic considerations for the determination of bending stress at the endurance limit was justifiable in the case of these two materials. Such a conclusion could not have been reached by any form of static test.

Results of Tests on the Machine

Some results of tests made on two light alloys are given in Figs. 10 and 11. Those in Fig. 10 refer to tests made at 20°, 100°, 200°, and 300° C. on specimens machined from standard sand-cast bars of aluminium—12% silicon alloy to B.S.S. 2L33. The scatter of results obtained is of the order generally found with cast materials. The endurance limits at 50×10^6 cycles of stress are given

TABLE I

Temperature of Test °C.	Endurance Limit tons/sq. in.	Ratio of Endurance Limit to U.T.S. at same Temperature
20	±3·3	0·31
100	±2·8	0·30
200	±2·25	0·36
300	±1·6	0·39

in Table I. The final column shows that the ratio of endurance limit to U.T.S. rises with the test temperature.

The results in Fig. 11 refer to tests made at the same temperatures on similar specimens of aluminium—5% silicon—3% copper alloy to D.T.D. 424. It will be noted from the curves of Fig. 11 that the endurance of speci-

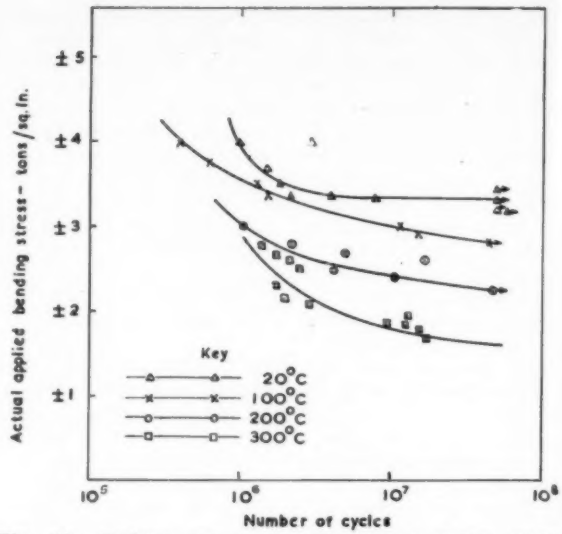


Fig. 10.—Fatigue curves for material to B.S.S. 2L33 tested at 20°, 100°, 200°, and 300°C.

mens tested at 200° C is greater than that of specimens tested at 100° C. for lives in excess of about 2×10^6 cycles of stress, this corresponding to about 11 hours of testing time at temperature. Clearly the properties of this material were changing at the higher temperature, and this was confirmed by the results of hardness tests made on specimens held at the two temperatures and tested at intervals up to one week. The specimen held at 200° C. increased in hardness while that held at 100° C. retained constant hardness.

TABLE II

Temperature of Test °C.	Endurance Limit tons/sq. in.	Ratio of Endurance Limit to U.T.S. at same Temperature
20	±4·0	0·38
100	±3·55	0·35
200	±3·9	0·41
300	±2·7	0·45

The endurance limits found in these tests are given in Table II. It should be noted that the U.T.S. values were determined from specimens held at the test temperature for only one hour before being pulled, and it is now

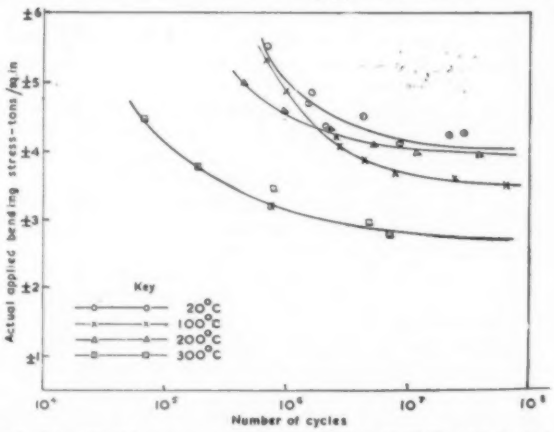


Fig. 11.—Fatigue curves for material to D.T.D. 424 tested at 20°, 100°, 200°, and 300° C.

realised that a more satisfactory value of the ratio of endurance limit to U.T.S. might have been obtained had the tensile specimen been held at the test temperature for a much longer time, preferably for the time corresponding to 50×10^6 cycles in the fatigue tests—i.e., 278 hours = approximately 12 days.

Conclusions

The rotating load fatigue testing machine described in this report enables fatigue tests in flexure to be carried out at elevated temperatures, while at the same time permitting accurate measurement to be made of the specimen temperature. A dynamic method of calibration developed for use with the machine makes possible the determination of the stress-strain relationship of the test specimen at the high rate of stressing applying in fatigue testing. The dynamic limit of proportionality has been shown to be much higher than the static limit in some materials at elevated temperatures. At sufficiently elevated temperatures there may be no limit of proportionality under static testing conditions and the relationship of stress to strain at high rates of stressing can be determined only by dynamic calibration. The dynamic calibration method makes it possible to decide in any given instance whether or not it is justifiable to assume elastic stressing in computing bending stress from applied force and specimen dimensions.

While complete endurance curves have not so far been determined at temperatures higher than 300° C., individual tests have been run for lengthy periods at 500° and 700° C. on specimens of aluminium bronze. No difficulties were experienced in carrying out these tests, and it is certain that the machine can be used for the determination of endurance limits on suitable materials at all temperatures up to 700° C., which is the temperature limit of the present design of furnace. It appears that tests at still higher temperatures could be carried out with a suitable furnace and with the possible provision of some form of cooling for the ball-race—e.g., a jet of cold air impinging on it.

The machine is also suitable for carrying out the determination of endurance limits at sub-normal temperatures and also under those conditions generally referred to as "corrosion-fatigue conditions."

Appendix
Description of the D.C. Motor

For successful operation of the machine it is essential that it be driven at constant speed, since the magnitude of the rotating load varies as the square of the speed of revolution of the out-of-balance mass. Synchronous motors do not give sufficiently constant speed under present electricity supply conditions, when large frequency variations are experienced. The difficulties arising from these conditions have been overcome by employing a $\frac{1}{2}$ h.p. 220 v. D.C. motor to power the machine, this motor incorporating a centrifugally-actuated contactor governor which limits the speed variation to less than $\pm 1\%$ on 3,000 r.p.m. for a line-voltage variation of $\pm 10\%$.

The motor is shunt wound and includes in its field circuit a control resistance which is approximately equal to the resistance of the field winding—namely, 800 ohms. Mounted on the rear end of the motor shaft is a small assembly consisting of a fixed and a movable contact, together with two slip rings. Each contact is connected to a slip ring, and both ends of the field-control resistance are led to the slip rings through small brushes. The movable contact is loaded by a small helical spring and is restrained in an open position when the motor is stationary. The spring tension is adjusted so that on attaining a speed of 3,000 r.p.m. the contactor is closed by centrifugal force, thus short-circuiting the field-control resistance and increasing the field current. This increase of field current results in the motor slowing down to a speed below 3,000 r.p.m. when the contactor again opens, reduces the field current and increases the motor speed. The motor thus hunts over a small speed range having a mean value of 3,000 r.p.m., this range depending upon the sensitivity of the governor.

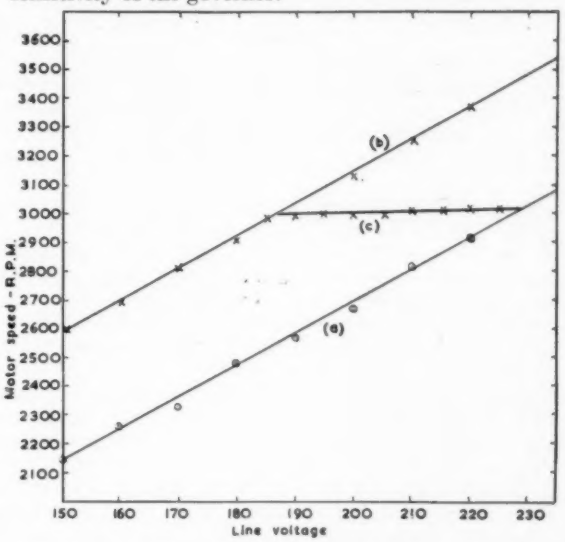


Fig. 12.—Speed/line-voltage characteristics of D.C. motor.

The speed/line-voltage curves for the motor are given in Fig. 12. Curve (*a*) is the normal, ungoverned characteristic, and curve (*b*) is that obtained with the field-control resistance in circuit and the governor disconnected. The governed characteristic is curve (*c*), and it is seen from this that the speed variation corresponding to a line-voltage variation of 185–230 volts is 40 r.p.m.

To reduce line-voltage fluctuations to a minimum, the D.C. supply to the machine is provided by a 3-phase metal rectifier. The unsmoothed output of such a rectifier has a ripple of approximately 5%, but has a smaller mean-voltage variation than the D.C. mains.

The furnace and motor control-circuit is shown diagrammatically in Fig. 3. The double-relay *L* is shown in the off position. In the running position—i.e., relay on, the positive line is connected to the machine, and the whole of the variable starting resistance *R* is included in the armature circuit to limit the starting current taken from the rectifier, and is taken out of circuit when the motor is nearly up to speed. On fracture of the specimen the micro-switch is tripped and the relay *L* drops into the off position, breaking the positive line, and switching the resistance *R* across the motor as a load. Thus, because of the regenerative braking effect, the running down period of the motor is considerably shortened, the drop from 3,000–1,000 r.p.m., taking place in approximately one second, as shown by a cathode ray oscillograph record. This rapid pulling up of the motor is considered desirable to reduce the possibility of damage to the rotating head

when the constraint normally provided by the specimen is removed when fracture occurs.

Acknowledgments

The authors wish to thank the Director and Council of the British Non-Ferrous Metals Research Association for permission to publish this paper.

Availability of the B.N.F. High-temperature Fatigue-testing Machine

Arrangements for the manufacture of the fatigue-testing machine described in the above article have been made with the Inspector of Naval Ordnance, Admiralty Offices, Janson Street, Sheffield, 9, where enquiries regarding prices, etc., should be addressed.

Machining Work-Hardening Steels

By W. M. Halliday

The work-hardening of austenitic steels on machining is a well known phenomenon. In this article, the author discusses the means to be adopted in order to minimise the effect, and methods of dealing with parts which have already been work-hardened in earlier operations.

A CONSIDERABLE amount of valuable information has appeared from time to time concerning the work-hardening which may occur during the machining of certain stainless and alloy steels. In the main, such information has been chiefly concerned with describing the nature and extent of the work-hardening, how it occurs, and the means by which the machinist may avoid it.

Little has, so far, been published on the steps which may be taken to deal with work-pieces which have been accidentally work-hardened during one of the machining stages. The author is acutely conscious of this lack of guidance in connection with the machining of stainless steel components, particularly on screw automatics, where this trouble continually arises, and where it may lead to other tooling and setting difficulties, as will be discussed later.

Causes of Work-hardening

The various causes of work-hardening, during machining, are worth enumerating at the outset in order to remind readers of the many ways, often simple ones, in which this condition may arise. They are :—

Dull Tools.—Particularly on automatic lathes, drilling machines and milling machines, dull tools are one of the most prolific causes of work-hardening of stainless steels. Twist drills and parting tools seem to be the most frequent sources of trouble due, it is suggested, to the relatively severe load imposed on what are often the weakest cutting tools in a set-up.

Intermittent or Interrupted Feed.—Even sharp and correctly ground cutters may give rise to work-hardening if the rate of feed is suddenly retarded. Any change of feed rate during cutting inevitably results in a slight interruption in the cutting action of the tool, and if the speed of rotation of the work-piece is high, as is often the case in automatics, a certain amount of rubbing between the work-face and the tool must occur. This will tend to work-harden the surface.

Rubbing of Tools.—Where tools are incorrectly ground, particularly in respect of insufficient clearance rake, slight rubbing action will develop : this will again result in the hardening of the work-piece at the point of cut. It often occurs when a machine is being set-up, as the setter usually runs the machine through a few cycles using hand feeds and the feeding action is usually far from being uniform, steady or continuous.

Excessive Generation of Heat.—If, for any reason, the heat at the cutting-point is allowed to exceed a certain limit, the danger of work-hardening is increased. A high speed of the work-piece or cutter, too fierce a feed, a blunt tool, incorrect rake angles, lack of coolant, wrong kind of coolant, wrong shape of cutting tool, insufficient chip clearance, etc., may all contribute to the undue generation of heat.

Spindle Float and Slide Wear.—These two factors often give rise to harmful work-hardening conditions which are sometimes difficult to diagnose and correct. For example, if the spindle bearings of an automatic machine become worn and a certain degree of movement exists, a point will be reached, during the cutting cycle, when such slackness will be taken up by the push of the cutters, which at that moment will not be penetrating the material at the prescribed rate of feed and rubbing and work-hardening will take place. Similarly, slack work slides on the machine may allow the tool to idle and rub on the workpiece for a few revolutions ; this may be sufficient to cause work-hardening.

Insecurely Held Tools.—In automatic screw machine, drill press and capstan lathe operations, lack of effective end retention of the tools will often give rise to work-hardening. Where twist drills, employed for boring holes in bar, are not positively and securely restrained against endwise movement within the holder, the additional pressure imposed as the cutting edge becomes blunted may cause the drill to creep back within its holder. This, to some extent, negatives the normal feeding action of the machine and allows the tool to idle instead of cutting.

Insecurely Held Work-pieces. Similar action results when the stock is ineffectively held in the lathe chuck, collet or fixture. This is a common feature of automatic lathes employing spring collets of the draw-in type. A worn collet, or one having insufficient draw-in movement, will not grip the work-piece sufficiently tightly, thus allowing it to be pushed away by the tool when the latter becomes slightly blunted, or when it is operated with too heavy a feed or cut.

Machine Defects.—Under this heading may be included all those minor defects which develop during the operation of most types of machine tool, and whose effect is to stop the machine outright or to retard its speed of operation. In the first class may be placed broken belts, slipping belts, overheated motors, faulty clutches and

fracture of such things as springs, levers, pins, etc. The second class includes such items as poor lubrication, mal-adjusted slides, inadequate means for locking slides, loose gears, cams or levers, accumulation of dirt at vital points and indeed any of those minor points which may slow down the machine. Reference will be made to these two items later in the discussion.

Preventive Measures

In considering the steps to be taken by the intelligent machinist, in order to avoid work-hardening, it should be stated at the outset that much can be done to obviate the trouble by careful preliminary checks of tools, machine settings, operations and all accessory equipment such as motors, belts, lubrication, coolant, etc.

Extra care should be taken to ensure that all tools are correctly sharpened, honed and lapped to the keenest possible cutting edge. In this connection, the author has found it helpful and economical to issue to each tool setter the correct type of hand lap for restoring the cutting edge of the tool. This provision has ensured that perfectly flat laps of the correct type are employed, in contrast to the previous procedure, in which each tool setter was left to find his own laps, and was consequently often satisfied to use worn and badly shaped ones. Provision should also be made for the maintenance of correct tool angles on sharpening. This will involve making suitable angle fixtures for holding the tools during this operation.

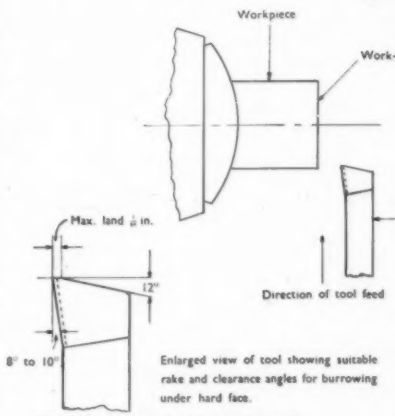


Fig. 1.—Special burrowing tool.

Setters and machinists should be instructed that changes in feed rate are forbidden during cutting operations, whether these be on a production run or during setting-up. In this way, interruptions and intermittent feeding should be confined to unavoidable occurrences such as machine breakdowns.

The provision of proper grinding fixtures to ensure correct cutting angles should do much to avoid rubbing of the tool on the job. Apart from the causes mentioned previously, rubbing may be due to out of square tool-posts, inadequately clamped posts, badly adjusted slides, etc. It should be an essential part of the setters' duties to check such points before work-hardenable materials are machined.

In order to avoid excessive heating, the setter should check the amount and quality of the coolant as well as the speeds and feeds to be used.

Other checks and adjustments which should be made by the setter are: (1) Adjustment of the spindle play and slide movements; (2) Check on the security of the tool; (3) Check on the ability of collet chucks or gripping fixtures to hold the work against the cutting pressures employed.

When changing over a machine to stainless steel, the maintenance engineer should be asked to check the motor, belt adjustments, fastenings, ability to take the drive, lubrication, clutch adjustments and cleanliness so that everything possible is done to prevent interruption or slowing down of the machine.

Much of this fairly comprehensive procedure, combining the activities of the maintenance engineer, the tool setter and the tool-room staff, can be developed into a scheme of standard shop practice which will automatically be applied where work-hardenable materials are to be machined.

Much more could be written on the subject of preventive measures, but the foregoing will be sufficient to illustrate the general lines on which such measures should be based.

Corrective Measures

It now remains to outline the means whereby parts which have already been work-hardened may be machined.

Annealing.—Whilst the most satisfactory way of dealing with such parts is the removal of the effects of work-hardening by an annealing operation, in most cases this is impracticable. The softening temperatures of these steels are usually high, and with parts of slender proportions warping could easily occur. Again, with partially finished parts, the accuracy of some of the finished dimensions might be affected.

Fig. 2.—Method of removing work-hardened layer.

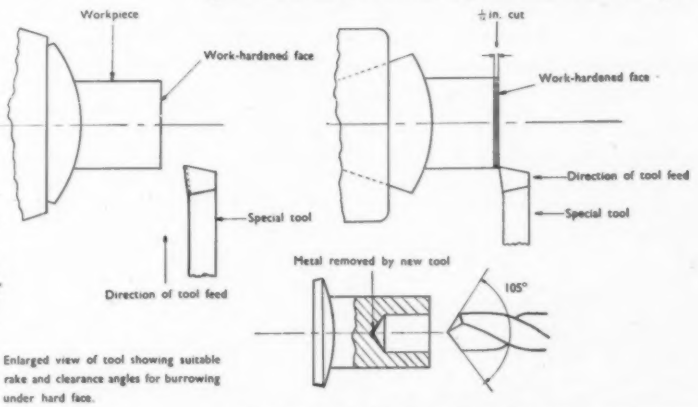


Fig. 3.—Modified drill point for penetrating work-hardened layers.

In cases where a general heat-treatment is not practicable, local heating by means of an oxy-acetylene flame has been used. It cannot be too strongly emphasised, however, that heating of these steels may cause changes in the micro-structure of the material which may result in corrosion and other troubles in service. It is not advisable, therefore, to apply any heating methods without expert advice on the procedure to be adopted.

Grinding.—The most obvious method of dealing with material work-hardened on the surface, is to remove the hardened layer by grinding, where dimensional considerations permit. A soft grade of grinding wheel should be used, as there is less tendency to glaze and rub, due to the wheel being overloaded with particles of material. Such wheels will, therefore, retain their clean-cutting properties longer than will a hard-grade wheel. During grinding a plentiful supply of coolant should be used. In most cases the removal of as little as 0·010 in. will be found quite sufficient to enable the cutters to

resume their normal cutting. There are, of course, many cases where such grinding is not possible, due to the inaccessibility of the hardened surface ; in some such cases small hand grinders of the flexible drive or pneumatic type may be used.

Tooling Methods.—It is surprising the number of seemingly difficult machining problems, arising from work-hardening effects, which can be successfully solved by making simple alterations to the normal tool. This is particularly the case in automatic lathe work. The tool should be lipped away to approximately 12°, taking care to leave a short land $\frac{1}{64}$ in. wide up to the cutting edge. This land should lie parallel to the axis of of the bar being turned. The tool should also be given a front rake of 5° and ample side rake of between 8° and 10°, and should be ground so that the cutting edge tapers almost to a point. A tool of this shape is illustrated in Fig. 1. It will be better able to burrow beneath the hardened surface, as less resistance will be presented to it, due to its extra rakes and pointed shape. The shank should be made short and strong, using the largest section of tool bar permitted by the tool-holder.

When work-hardening occurs, the usual round-nose tool will be replaced by the special tool, the cut being started from the outside and the tool fed by hand, using a much slower spindle speed. The chiselling action of the special tool will, in most cases, enable the hardened skin to be penetrated and removed.

In the case of work-hardening during parting-off, a similar method should be adopted. The special parting-tool should not have any top rake, whilst the front angle should be kept small, say 3°, just sufficient to remove the component without producing a pip. Needless to say, the shank of such a parting-tool should be of ample strength, in order to avoid any tendency to deflect under the increased load necessary in removing hardened material.

Much can be done to avoid hardening effects on automatics by designing the slide and turret operating cams to give five feeds, equal to about half those normally used for free-cutting mild steel. In laying out such cams, it is helpful to make them produce a slight drop back as the tool returns to the open position after completing its cut. The drop back need only be about 0·005 in., sufficient to give a little extra clearance to the tool. The author has often found that tools have been dulled by the rubbing action caused by the trailing tool on its return stroke after cutting.

The importance of correct rake and clearance angles cannot be too strongly emphasised, if work-hardening is to be avoided, and fixtures for re-grinding are an absolute necessity.

It is often possible to remove work-hardened layers by re-setting the tool so that it is fed into the work-piece from a point *behind* the hardened face, the feed being in the direction of this face. Feeding should be by hand and the speed should be considerably reduced.

Another useful method consists of taking a series of cuts at right angles to the hardened surface. For example, in the case of a cylindrical bar whose end face has been work-hardened, a number of cuts should be taken reducing the diameter for a distance of say $\frac{1}{32}$ in. up the bar, until the hard face is removed in the manner shown in Fig. 2. In this way, the cutter is applied to the hard surface in the direction of its smallest depth, thus giving it a better chance of getting under the skin.

A further method uses a drill at very slow speeds to get through the hard layer at the centre. A pointed lathe tool is then started in at the rim of the drilled recess and fed outwards. A moderately heavy cut can usually be taken. In this method again the cutter can get a start on the hard material to be removed.

Work-hardening in Drilling

Specific recommendations on the speeds to be used for drilling stainless steels are inadvisable, as each job will present its own problems, but a good general basis would be between half and two-thirds of the speeds normally used for mild steel with feeds about 20–30% finer. With these figures as a basis, alterations can be made in the light of experience.

Even greater care is necessary with twist drills than with lathe tools, if work-hardening is to be avoided, because of the flexilibity of the drill. The drills used for stainless steel should be shorter than normal drills so as to obtain greater rigidity. Grinding of the drills should be accurately performed, preferably by machine, and the cutting edges should be lapped.

Drills used for penetrating hard layers should have their included angle changed from the standard 118° to 105°, as shown in Fig. 3, so that the drill can take up the pressure more gradually and the hard face be removed in fine cuts.

Standard twist drills can often be greatly improved, for drilling austenitic steels, by the following modification of the cutting-edge clearances. The drill should be ground, in the machine, to the usual 12° clearance angle away from the cutting edge, and then set-up so as to obtain a smaller clearance angle, say 8°, for $\frac{1}{64}$ in. from the cutting edge. This will be found particularly helpful in the case of twist drills smaller than $\frac{1}{4}$ in. in diameter, since greater support is given to the cutting edge.

In order to minimise the generation of heat, the flutes of all twist drills should be highly polished and copious supplies of coolant should be delivered to the cutting point, particularly in the case of small diameter deep holes.

Miscellaneous Recommendations

In conclusion, reference should be made to a few general precautions which can be taken with advantage on automatic machines. The collet sleeves provided on the spindle for gripping bars should be glass hard and should be given an extremely high polish ; otherwise the surface of the bar will be rubbed during feeding and some hardening may occur, resulting in dulled tools. All bars should be well cleaned and have all burrs removed before insertion in the machine, and every effort made to prevent the bar surface being marked.

As a coolant, "Frapol" or "Duckham's Special Purpose" cutting oil will be found to give excellent results if used undiluted,

If the foregoing recommendations are rigorously carried out on all stainless steel machining operations, work-hardening can be kept to a minimum and the resultant waste of labour and material can be largely avoided.

MR. ERNEST GOLDSCHMIDT, P.O. Box 274, Mogadishu, Somalia, has been appointed by Specialloid, Ltd., their sole main distributors for piston assemblies, piston rings, cylinder liners, valve seatings, replacement bearings and bushes, anti-friction white metals, bronzes and crankshaft grinding machines, in the territory of Somalia.

Factors Influencing the Spheroidisation of Steel

By E. V. Tull

"Spheroidisation is essentially a process involving diffusion, and is best carried out by isothermal treatment at a temperature as near as possible to, but below, the Ac_1 point, followed by a fairly rapid cool. Cold-work accelerates this process, the acceleration being greater the greater the amount of previous cold-work. The addition of 1·4% chromium to a 1% carbon steel improves its spheroidisation characteristics in all respects." The foregoing is the author's summary of an investigation he carried out, the main objects of which were to study the process, examine the effects of cold-work and of the addition of chromium, attempt to establish a relationship between cold-work, time and temperature in a cycle, and to study the effects on wire "as rolled" and normalised. The preliminary work involved a careful study of previous work on the subject, a review of which is given in the present article.

LOW-CHROMIUM high-carbon steels are widely used in the manufacture of ball-bearings. The smallest sizes of ball-bearings are made from wire from which slugs of the correct length are cut off and cold pressed to approximate form. Extreme hardness and perfect spherical form are essential requirements. The process by which these requirements are fulfilled is fairly standard in general, although it may vary appreciably in detail from plant to plant. The heat-treatment involved consists of: (1) Normalising the "as rolled" wire; (2) spheroidisation of the normalised wire; and (3) hardening.

Normalising refines the grain and reforms the carbide envelopes present around the austenitic grains into smaller and more spherical forms, speeding up the process of spheroidisation. The second process transforms the lamellar pearlitic carbide of the normalised wire into a spherical or "spheroidised" form, the resulting structure being a fine dispersion of carbide globules in a matrix of ferrite. This latter process puts the steel in the most machinable condition; facilitates cold-working and gives it a better grain structure when finally hardened, a structure which provides the optimum wear-resistance of the final bearing. The hardening process puts the bearing into the extremely hard condition required in service.

Of these three processes, the spheroidisation is by far the most time-consuming, and it seemed possible that a study of the fundamentals of the process might lead to the development of the most efficient and the shortest spheroidisation treatment, consistent with the requirements of the ball-bearing industry, and thus have considerable economic importance. At present this process consists of a prolonged heating just below the A_1 point, followed by a slow cool lasting several hours down to approximately 600° C., and then finally cooling at the normal rate of the furnace. The temperatures used, and the relative preponderance of the soaking time and the slow cool, vary in different plants, but it is essential that complete spheroidisation and uniform distribution of the carbides should be achieved before the hardening operation. Experience has shown, however, that the spheroids should not be too large, as the particle size of the carbides affects the rate at which they go into solution during the hardening heat.

In a recent investigation* made by the writer to study the effect of spheroidisation, particularly with regard to the time involved in spheroidising normalised steel, it was necessary to study previous work on the subject, and it is believed the following critical survey will be of value to many readers.

* Carried out under the supervision of Mr. A. Preece, M.Sc., University of Leeds, and forming part of a thesis for an Honours Degree.

Early Work on Spheroidisation

The earliest work on spheroidising is reviewed in two papers by Howe and Levy[1, 2]. They held the classic view that austenite transforms to sorbite, then to pearlite, and that with prolonged holding at temperatures below the critical, the pearlite "divorces" to ferrite and spheroids of carbide. They found that masses of definitely lamellar pearlite could occur very near to regions in which the original pearlite has been completely spheroidised, and that the degree of spheroidisation of the pearlite varied widely in the same section. They used steels with a wide range of carbon contents and heated them all to 900° C. or above before cooling. In the light of modern work, it is now clear that the use of such temperatures would render complete spheroidisation extremely difficult. They stated that heating to 1,200–1,300° C. prior to cooling, as well as holding for a long time at lower temperatures (around 900° C.) retarded spheroidisation.

Although the very earliest observations on spheroidisation were made in this country by Arnold[3] and by Stead[4], not much additional information was published here until Whiteley[5, 6] in 1918 showed that pearlite which had been cold-worked spheroidised much more readily at 650° C. and 680° C. than the pearlite in the "as rolled" condition of a hot-rolled bar. Four years later, the same author, whilst attempting to establish accurately the Ar_1 point of carbon steels, observed that he obtained spheroids when his steels were cooled to 710° C. and 705° C., providing his heating times were very short—3 to 5 mins.—and his heating temperatures were not much over the critical. He did not obtain completely spheroidal structures. More recently, Carpenter and Robertson[7] studied the transformations in carbon steels during slow cooling and they showed that the structure formed from a relatively low heating temperature was mainly spheroidal, whereas that formed from a high heating temperature was lamellar.

Few papers had been published in the U.S.A. on spheroidising since those by Howe and Levy until comparatively recently. Emmons[8] showed that the relative amounts of lamellar and spheroidal pearlite in annealed tool-steel could be altered by the rates at

which the steel was allowed to cool from above the critical. MacPherran and Harper[9] discussed the "loneal" treatment for producing a spheroidised structure in hypo-eutectoid steels, the treatment consisting of very long heatings, up to 72 hours at 675° C. Foley, Clayton and Remmers[10] discussed the effects of cooling rates from 750°C. on the properties of a 0·75% C, 0·52% Mn steel. They found that the slower the cooling, the more spheroidal was the product, but they were of the opinion that pearlite formed first and then spheroidised during the retarded cooling.

Recent Work on Spheroidisation at Sub-critical Temperatures

It is now generally accepted that sub-critical spheroidisation is a process involving the solution and diffusion of carbides in ferrite[11] with an accompanying decomposition or modification of the transformation products of austenite originally present.

The exact manner in which these transformation products change to produce spheroidal structures is not so well understood. It is known, however, that sorbitic pearlite and sorbite obtained by tempering martensite both spheroidise at a greater rate than does lamellar pearlite.[12] This is attributed to the fact that the cementite plates in sorbitic pearlite are very much smaller than those in lamellar pearlite, and thus they probably act as nuclei for spheroidisation—whereas in lamellar pearlite, the cementite plates are too large to act as nuclei and must sub-divide to produce plates small enough to act as such. In sorbite, the minute dispersion of carbide particles constituting its structure readily act as nuclei for spheroidisation.

Considering pearlite, N. T. Belaiew[13] states that lamellar structures are essentially unstable and tend to become spheroids. In the course of this evolution each lamella contracts into grains, the diameter of which, at the end of the period of complete disintegration, is 15 to 16 times the width of the lamella. This evolution is very slow and is affected by annealing.

The inherent instability of the lamellar structures is well demonstrated by the fact that years of service at temperatures well below those that will produce rapid spheroidisation may finally produce it.[12]

The reason for this instability is that the lamellar structure does not represent complete physical equilibrium, since such equilibrium requires that smaller particles should aggregate to form larger, or that particles should modify their shape, until a condition is reached in which surface forces become negligible. This effect may be regarded as one of surface tension.[24] That very small crystals of a substance are labile in the presence of larger crystals of the same substance and of a solvent is a thermodynamical necessity, and has been proved experimentally for calcium sulphate in water,[14] and in other instances. In the spheroidisation of the cementite lamellae of pearlite, the first stage is the separation of these lamellae into a series of beads by the formation of constrictions at intervals,[15, 22] as mentioned previously. With longer heating, distinct globules are formed, which in time may aggregate to form larger globules. This process must involve the passage of carbon into solid solution in the ferrite, although the solubility is very small, being only 0·035% at 700° C., and falling rapidly with falling temperature.[16] That the process is essentially one of diffusion is shown by the work of Bailey and Roberts,[17] who found that by plotting the logarithm of the rate of spheroidisation against the reciprocal of the absolute temperature, a straight line relationship was obtained. Thus two of the factors contributing to the decrease in the rate of spheroidisation with decrease in temperature are :

(*a*) Decrease in the rate of diffusion of carbide in the ferrite.

(*b*) Decrease of the solubility of carbide in the ferrite.

Consideration of these two factors alone makes it obvious that for maximum rate of spheroidisation, a temperature as close as possible to the critical, but below it, should be used.

The rate at which such carbide particles redissolve to form a solid solution will depend on the ratio of their surface to their mass.[18] Calculation shows that the rate of solution of globular cementite may be either greater or less than that of the lamellae, according to the dimensions, but it has been found by various workers[19, 20, 21] that other factors intervene, the process in the lamellar structure beginning at the grain boundary and proceeding inwards, whilst each globule dissolves in the ferrite immediately surrounding it. It will thus be seen that the change from a pearlitic to a spheroidal structure is highly complex. The literature on this process is extensive, but the conditions involved are discussed in a paper by Korber and Koster.[23]

Several workers have found that the finer the initial structure, the faster is the rate of spheroidisation—this is illustrated in practice by the fact that normalised steels spheroidise at a higher rate than do annealed steels.[25] This effect of fineness applies both to the metallographic structure and to the grain size, thus sorbitic pearlite spheroidises faster than does lamellar pearlite, and fine-grained steels spheroidise faster than do coarse-grained steels.[12] This is probably due to the fact that the diffusion distances involved in the finer structures are less than those involved in the coarser structures ; but other factors, such as the mode of solution of pearlite (see above), have also an appreciable influence on this phenomenon.

Like other processes depending on diffusion, spheroidisation is greatly hastened by mechanical deformation. Some of the most recent work on the effect of cold-work on spheroidisation has been carried out by C. L. Shapiro.[26] He found that cold-work prior to spheroidising below the critical temperature accelerates the process of spheroidisation, and the greater the amount of deformation, the greater is this acceleration. Also, cold-work prior to normalising slightly increases the rate of spheroidisation, whilst after normalising cold-work greatly increases this rate. This seems to bear out the theory that the increased rate of spheroidisation is due to the increased reactivity of the strained cold-worked steel ; as this reactivity would be largely removed by normalising, which involves recrystallisation. Shapiro also describes a number of processes of change of structure by which pearlite in annealed steels changes to spheroidised cementite—again indicating the complex nature of this change.

In the long heatings involved in present-day spheroidising processes, graphitisation presents a serious problem. Laszlo[27] offers an explanation of this phenomenon as it is found in the spheroidising of steel wire. He refers to previous work by N. Greenwood, who found that it was not the cementite particles which decomposed to give graphite, but the ferrite surrounding them which did so, and that such decomposition probably occurred during

cooling. Laszlo then considers the conditions involved in cooling from the point of view of the tessellated stresses set up in the structure of the steel, and shows that during cooling the precipitation of carbon out of the solid solution of cementite in ferrite should be greatly facilitated by these stresses. He adds that it is questionable whether the cementite spheres would decompose at all during cooling. Shapiro[26] investigated the effect of various alloying elements on the rate of graphitisation and found that silicon, copper, aluminium and cobalt accelerated the process, whereas the carbide-formers, chromium, tungsten and vanadium, retarded it. Smith, Miller and Tarr[25] investigating low-carbon and low-carbon molybdenum steels found that the rate of graphitisation was approximately the same for steel in both the normalised and annealed conditions, and that the rate increased with increase in temperature.

The lowest temperature at which spheroidisation can be effected is somewhere above 350° C., but the time involved is extremely great, even when accelerated by cold-work.[28] The lowest practical temperature is about 675° C., and temperatures between this and the critical are the most frequently used.

Recently, much research in Germany has been directed towards utilisation of the heat of rolling in the heat-treatment of steel. Walzel, Werner, and Schneider[29] investigated the effects of three different treatments on the hardness, microstructure and machinability of a number of copper-bearing steels with carbon contents over the 0·37–1·08% range, some of which were alloyed with chromium and nickel. The three treatments were :

(*a*) Annealing after cooling on a cooling bed in the ordinary way.
(*b*) Annealing after hardening from the heat of rolling.
(*c*) Annealing after hardening by special heating and quenching.

It was found that, in general, treatment (*b*) produced the greatest hardness in low-carbon steels and the lowest hardness in high-carbon steels. The structure after treatment (*b*) was the most uniform and consisted of fine spheroidal cementite.

Recent Work on Austo-spheroidising

The first workers to demonstrate conclusively that a spheroidal product could be obtained by direct transformation from austenite were Payson, Hodapp and Leedon.[30] This monumental paper, with its disruption of previous theories, introduced a completely new means of attacking the problem of spheroidisation, and was the foundation upon which much work and development has been and still is being carried out, in both the scientific and commercial fields.

Previously, the phenomenon had been observed on several occasions, but had been misinterpreted in that it was assumed that spheroidite was a transformation product of pearlite. Payson, Hodapp and Leedon showed that spheroidal carbides were formed directly from austenite, if the temperature to which the austenite is heated, and at which it is subsequently allowed to transform, is carefully controlled. They used steels of the plain-carbon type with carbon contents from 0·33–1·16%. The formation of spheroidal structure was in direct contradiction to the view that austenite transforms only to lamellar pearlite at temperatures not far below the critical.[31] Grossman[32] had previously found a similar phenomenon in the very slow cooling of a steel from 760° C., but he implied that the composition of the steel, together with details of the cooling cycle were responsible for this exception from the rule.

In comparing this process with the sub-critical spheroidisation process, they showed that the structures given by the latter still contained some lamellar pearlite even after 50 hours at temperature 725° C. ; whereas the structures obtained by austo-spheroidising, involving a much shorter time, were completely spheroidal. They determined the temperatures at which all lamellar carbide would be eliminated from the original structure—known as " the minimum austenitising temperature "—and all steels were heated at this temperature before transformation, in order that the resultant structure should contain no lamellar carbides.

To establish the times required for the completion of transformation at various temperatures, they obtained time-temperature-transformation curves for the upper part of the transformation region, for these steels. As a result, they found that the rates of transformation at these high temperatures were much slower for some steels than for others, but all steels transformed directly to spheroidal carbides at the highest transformation temperatures ; to lamellar pearlite at lower temperatures, and to mixtures of spheroidal and lamellar pearlite at intermediate temperatures. The range of transformation temperatures in which only a spheroidal product would form varied with the steel. The higher carbon steels were relatively easy to spheroidise because the transformation rates were rather fast, and the product was spheroidal over a fairly wide range of transformation temperatures. The lower carbon steels were rather slow to transform at temperatures when only a spheroidal product was formed, and the range of temperature in which the transformation product was spheroidal was quite narrow ; these steels were, therefore, more difficult to spheroidise completely.

It was found that the formation of a spheroidal product could be made easier by a short heating (2 hours or so) at a temperature just below the critical (715°–725° C.) before austenitising. This treatment increased the transformation rate of the austenite, and decreased the amount of lamellar, or elongated carbides, in the transformation product. This treatment was especially beneficial in the case of the lower carbon steels.

In hypo-eutectoid steels, it was found that as the austenitising temperature was raised, the amount of lamellar pearlite in the transformation product at once increased ; and the transformation rates at the higher temperatures were also appreciably decreased. The effect was much less in hyper-eutectoid and eutectoid steels, the effect decreasing rapidly with increase in carbon content (the 1·16% steels could be heated to 860° C. without forming lamellar pearlite when transformed at 725° C.). It was also observed that prolonged heating at lower austenitising temperatures was equivalent to shorter heating at the higher austenitising temperatures, in regard to the subsequent rate of transformation and the formation of lamellar pearlite. As before, the higher carbon steels were the least sensitive to this effect.

Experiments on partially decarburised bars of hyper-eutectoid steel showed that the steels of intermediate carbon content (0·3–0·7% C) had a slower transformation rate than either the low-carbon hypo-eutectoid or the high-carbon hyper-eutectoid steels, and were thus the more difficult to spheroidise.

The minimum austenitising temperature varied with the steel in the range 740°–760° C. and the transformation temperature between about 715°C. and 725° C., for the best results. The carbon content of the steel controls the temperatures within which austenite must be heated (see above) and transformed, for the production of a spheroidal product; the hyper-eutectoid steels allowing most deviation from the optimum conditions, and the intermediate carbon steels least.

The holding time at austenitising temperature recommended in the procedures the authors put forward was one hour, and the time allowed for transformation between three and six hours. In discussing the application of such procedures to practical annealing operations, the authors emphasised the need for accurate temperature control to within a few degrees. It was probable that relatively large loads in batch-type furnaces would heat sufficiently slowly to austenitising temperature to make it unnecessary to hold the temperature purposely in the sub-critical region in the case of steels requiring a sub-critical preheat. Also the cooling rate of large loads in a well-insulated furnace may be sufficiently slow to allow transformation to be completed at the high temperatures in the case of hyper-eutectoid steels, thus eliminating the necessity for holding the temperature at some level during cooling. Under such conditions, a steel could be completely spheroidised by furnace cooling at the "natural" rate of the loaded furnace, and the load could be discharged from the furnace when the steel temperature had dropped to about 675° C. and allowed to cool in air. For the low-carbon steels (0·3–0·7% C), very slow cooling from austenitising temperature down to transformation temperature was undesirable, because the time spent in cooling would be much better used at holding temperature. Under any circumstances, continued slow cooling after the steel temperature had dropped to about 675° C. was of no advantage.

In discussing the possible mechanism for the formation of a spheroidal product by direct transformation from austenite, the authors hold the view that undissolved particles present in the austenite at the beginning of transformation act as nuclei for the formation of spheroids. In support of this theory, they refer to the fact that raising of the austenitising temperature, reduces the tendency of the austenite to transform to a spheroidal product—which is, in their view, due to the solution of a greater number of nuclei in the austenite. Their selection of "the minimum austenitising temperature" was based on the temperature at which the reaction: Ferrite + Pearlite = Austenite + Spheroids, would be complete in one hour or less. It was the "minimum" temperature consistent with such a condition, by reason of the undesirable effect of raising the austenitising temperature unnecessarily. In discussing the nature of these nuclei, the authors disproved the theory that they were residual carbides, since it was found that steels containing no visible evidence of residual carbides, even under a 1,000 magnifications, still gave a spheroidal product on transformation. It was possible, however, that such residual carbides in the hyper-eutectoid steels accounted for their ease of spheroidisation in comparison with the hypo-eutectoid steels, in which there is no pro-eutectoid cementite. It was, however, possible that particles other than carbides were present, after low-temperature austenitising, which would act as nuclei for spheroidisation. The identity of such particles and their solubility in austenite and ferrite remains to be established. If the austenitising temperature was raised high enough a lamellar product could be obtained in all steels on transformation at high transformation temperatures, as demonstrated by Mehl.[48] This was probably due to the solution of all nuclei, resulting in homogeneous austenite.

Whiteley[6] had previously observed the nucleation effect of residual carbides—he found that when nuclei of carbide were already present in a steel above the Ar_1 point, "globular cementite" was likely to be obtained on cooling below that point, in place of the usual lamellar form.

Additional confirmation for the nucleation theory described above has since been found by many workers, for example, Gensamer, Pearsall and Smith,[33] in investigating the isothermal decomposition products obtained from a 0·78% C, 0·63% Mn steel austenitised at 820° C., found that four hours holding at this temperature prior to quenching and transforming at 677° C. produced less spheroidal cementite than if the steel was held for only half an hour at this temperature. Some spheroidisation always occurred when the steel was transformed above 675° C.

As stated previously, the phenomenon of "austo-spheroidising" had been observed before the work of Payson and his associates, but had been misinterpreted. An example of such misinterpretation occurs in "Steel and its Heat-treatment," by D. K. Bullens.[12] Discussing "spheroidising annealing," the author states: "The recommended treatments consisted of . . . a thorough soaking either just below, or in, and slightly above, the Ac_1 range. Satisfactory spheroidisation and a quicker response occur when a temperature (say 760° C.) slightly above the Ac_1 is used." In all cases the soaking was followed by a slow cool. In the latter case, if the temperature exceeded a certain definite limit above the Ac_1, the cementite would appear again as "laminated pearlite." It is obvious from recent work, that the process using a temperature slightly above the Ac_1 referred to above is an austo-spheroidising process; a fact which is confirmed by the reference to the effect of raising the (austenitising) temperature on the nature of the transformation product. The process was misinterpreted in that the spheroidisation was assumed to take place above the Ac_1 point, whereas it actually takes place during the subsequent slow cooling, below the Ac_1 point. This misinterpretation resulted in an unnecessarily long holding time at austenitising temperature.

The application of "austo-spheroidising" to practical annealing operations followed quickly upon the publication of Payson, Hodapp and Leedon's paper, and two years later, a paper by R. F. Hafston[34] on its application to the manufacture of steel bearings was published. He used a steel conforming to the specification of the En.31 chromium-carbon steel, except for the addition of 0·13% of nickel. He investigated the steel isothermally to determine, under a definite set of conditions, the level at which austenite would cease to transform to spheroidite and begin to form pearlite, and the effect of austenitising temperature on the resultant structure. The Ac_1 point for the steel was 735° C., and he found that after austenitising at 776° C. for one hour, and transforming at progressively lower temperatures in each case, that pearlite began to form at a transformation temperature somewhere between 682° and 690° C. The size of the spheroids formed was the same at all the temperatures

investigated (two hours was allowed for transformation in all cases, before quenching) and thus it was obvious that the size of the spheroids could not be controlled by the temperature of transformation—it could be controlled by the time at these temperatures, however. He found that increase in the austenitising temperature increased the temperature at which pearlite formation commenced, this temperature approaching more nearly to the critical. He then investigated the formation of spheroidite during a furnace-cool, specimens being removed at various temperatures and quenched in water. After austenitising at 776° C. for one hour and cooling at approximately 30° C. per hour, it was found that transformation to spheroidite began quite rapidly at 728° C. and ended 35 minutes later at 710° C. The size of the spheroids obtained by furnace-cooling and by isothermal transformation were many times smaller than the spheroids in the structure generally accepted by a consumer of bearing steels. Thus, one specimen was furnace-cooled as described above to 690° C. and held there for 60 hours. This resulted in a coalescence to larger spheroids. The size of the spheroids thus depended on the time the steel was held below the critical. It was found that the rate of cooling from austenitising temperature to the critical did not influence the structure formed below the critical.

G. R. Brophy[35] describes a hardness method for determining the optimum austenitising temperature for some low-carbon steels. He states that the optimum transformation temperature to produce a spheroidal product is a temperature just above the nose of the transformation curve. It is recommended that all hypo-eutectoid steels should be pre-normalised from a temperature just above the Ac_3 point, to obtain the minimum grain size, and structural homogeneity. The small grain size so obtained persists through subsequent austenitising and spheroidising operations, producing a final structure of uniform dispersion of fine spheroidite in a ferritic matrix.

In Germany, research has been directed towards the utilisation of the heat of rolling in "austo-spheroidising"; just as it has been towards its utilisation in a sub-critical spheroidising, Schafer and Langenbach[36] have shown that the structure of ball-bearing steel is improved by annealing from the heat of rolling. The structure of the spheroidite thus obtained is more homogeneous than that obtained by the usual annealing procedure. When the proper rolling temperature is applied and the steel air-cooled to slightly above the Ar_1 point with subsequent annealing, not only is a very good annealed structure obtained, but economic advantages are also achieved.

Composition Effects in Chromium Steel

According to the iron-carbon-chromium diagram of Tofaute, Spoheuer and Bennek,[37] the En. 31 steel, used in the writer's investigations, is identical in constitution to a hyper-eutectoid carbon steel, except for the fact that the cementite, Fe_3C, of the plain-carbon steel is replaced by the isomorphous double carbide $(Fe, Cr)_3C$, in the chromium carbon steel. The latter may be regarded as a solid solution of chromium in cementite, the iron and chromium being in effect interchangeable. The equilibrium diagram for this steel is also identical to that for a plain-carbon steel in its layout, except for the fact that three-phase regions upon it appear as areas rather than as isothermic straight lines as in the plain-carbon diagram. Thus, in thermal transformations of any type, the same general considerations apply to both the plain-carbon and the chromium-carbon steels (of the En. 31 type).

In general, the effect of chromium is to render the austenite transformation more sluggish than in plain-carbon steels, and to slow up its inception; although Davenport and Bain[38] and Bain[39, 40] have shown that in transformation at constant temperature, once the transformation has started, at 715° C., it proceeds more rapidly than in a plain-carbon steel. It has also been found that chromium raises the temperature at which softening occurs on tempering, and also renders the process more sluggish. This was considered to result from the diffusion rate of the chromium-bearing carbide.[41a] A similar effect is observed in chromium steels which have been cold-worked, in that a higher temperature is necessary to bring about recrystallisation than in plain-carbon steels.[42a] Chromium assists grain growth in steels, so that chromium steel requires care in treatment to avoid a coarse structure.[26]

The use of chromium in ball-bearing steel confers several advantages on it as compared with a plain-carbon steel. The increased hardness after heat-treatment produced by chromium in a given mass serves to increase the wear resistance, and the presence of many finely divided carbides serves further to increase this property, which is one of the all-important factors in the service of ball-bearings. The effect of 1·5% chromium in a 1% carbon steel is to render the heat-treatment easier and less drastic; and the carbide particles after spheroidisation are smaller, more numerous and better distributed than in the 1% carbon steel.[44] Chromium is also beneficial in that it retards graphitisation during the long spheroidising treatment.[26]

Effect of Other Elements

The effect of small amounts of elements other than carbon on the reactions mainly due to chromium may be very marked, especially in the case of manganese.

1. *Manganese.*—Work carried out at the Union Carbide and Carbon Research Laboratories, Inc., U.S.A., on the effect of manganese on the critical cooling rate of steels containing up to 4% chromium, has indicated that manganese is one of the major controlling factors.[41b] It has a pronounced effect in increasing the sluggishness of the austenite transformation, thereby increasing the degree of air-hardening.[42b] The Ac_1 point is only very slightly lowered up to 0·9% Mn, but the Ar_1 point falls about 4° C. for each 0·1% increase in manganese. It has very little effect on the mechanical properties of the heat-treated steel up to 0·9% Mn.

In the annealed (slowly-cooled) condition, the structure of the steel is pearlitic, the amount of ferrite decreasing and the pearlite becoming finer with increase in manganese content. In spheroidisation, it has been found that manganese tends to retard coalescence and graphitisation.

2. *Silicon.*—Silicon has a mild effect in reducing the sluggishness of the austenite transformation on cooling, thereby increasing the critical cooling rate for hardening.[41c]. The Ac_1 and Ar_1 points are raised about 2° C. for each 0·1% increase in silicon content.[42b]. It has little effect on the tempering characteristics of the steel. In the annealed steel in the pearlitic condition, silicon has no appreciable effect upon the pearlite, but increase in silicon content results in grain refinement. In spheroidisation, silicon assists coalescence of the carbides and accelerates graphitisation.

Thus it will be seen that manganese and silicon tend to counteract each other in regard to their effects on the critical points, the austenite transformation, spheroidisation and graphitisation. In the case of the critical points, it has been found that 0·6% increase in manganese content compensates for the effect of 1·0% increase in the silicon content—i.e., manganese has the more powerful effect—this also being observed in the case of austenite transformation. With regard to the process of spheroidisation, it was found that 1·8% Cr, 1% Si, 1% Mn, 0·4% C steel showed definite coalescence after spheroidising for 10 hours just below the Ac point.[42b]

3. *Carbon.*—Dopfer and Wiester[45] measured the transformation of austenite at constant temperature magnetically, on specimens of 2 and 3% chromium steels. It was observed that a higher carbon content increased the time required to start transformation.

4. *Oxygen.*—The quality of ball-bearing steel regularly deteriorates as the oxygen increases.[46]

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The British Non-Ferrous Metals Federation

AT the recent annual general meeting of the British Non-Ferrous Metals Federation, the President, in presenting his annual report, said that the Federation had been strengthened by the joining of a further Trade Association, the Non-Electrical Copper Association.

During the year, close contact had been maintained with the officials of the Ministry of Supply responsible for their destinies. One of the subjects constantly under discussion had been the disadvantage under which the industry and its customers were working, as a result of the higher prices at which non-ferrous metals were sold to members of the Federation by the Ministry, compared with the world price at which foreign competitors could buy. The Federation also viewed, with some concern, the shortage of high-grade zinc.

The thanks of the Industry were due to the Federation and Trade Associations for their study of Standard Conditions of Sale, which had resulted in the publication, in March of this year, of the revised issue.

The President then referred to the establishment in conjunction with the British Overseas Mining Association and the British Non-Ferrous Smelters' Association, of the British Bureau of Non-Ferrous Metal Statistics. This work has been undertaken by the Federation's Statistics Department and the first number of the *Bulletin* is now available.

Referring to the Industrial Organisation and Development Act, whereby the Government can set up Development Councils to advise various industries, the President said that their house was in order at present and it was up to them to keep it so, and to show everyone that their ancient Industry was fully capable of controlling and of conducting its own destinies, and of continuing in the future, as it had done in the past, to contribute to the public good.

The following Officers were elected for the year 1948-49: *President*—Mr. H. W. Clarke, D.Sc.; *Vice-Presidents*—Mr. W. J. Terry, Mr. W. H. Henman and Mr. H. E. Jackson; and *Treasurer*—Mr. A. L. Johnson, M.A.

Some Characteristics of Sprayed Metal

By G. Tolley, M.Sc.

Metallisation Ltd.

The value of sprayed metal coatings for building up worn parts and in various schemes for protection against corrosion is now well established. In this article, the author outlines some salient features of metal-sprayed deposits for the benefit of those who are anxious to know something of the uses and limitations of the metal-spraying process.

THE recent appearance in this Journal of a short note on metal spraying[1] prompts a somewhat fuller treatment of some aspects of this subject. A communication dealing with some general properties of sprayed metal is especially desirable in view of the very limited knowledge of metal spraying which is shown by many industrial technologists. There is sometimes a tendency to use a metal-spraying pistol on every occasion without any consideration of practicability, while others evidence a complete disregard of the existence of a metal-spraying industry. In spite of the excellent detailed treatment of all aspects of metal spraying in the recently published book of W. E. Ballard[2] it is felt that a short survey of some salient features of metal-sprayed deposits will provide a useful introduction to many technical men anxious to know something of the uses and limitations of the metal-spraying process.

Before spraying on to any material, whether metal, wood or plastic it is necessary to prepare a roughened surface to ensure good adhesion between the sprayed coating and the underlying material. This is usually done by grit-blasting with angular steel grit of about 24-mesh. For special purposes, such as building-up work, grooving or knurling may be used to obtain a deposit having a higher resistance to shear than that on a blasted surface.

Adhesion

The question of the adhesion of the sprayed metal is often an important factor, whether the coating is applied for corrosion protection or for its structural importance as in building-up. Adhesion tests, are, however, difficult to devise and it is necessary to consider carefully the details of the job in hand before applying results obtained in laboratory adhesion tests. Nevertheless, such tests are of value in showing that metal-sprayed coatings can be applied having excellent adhesion to the basis metal. The method of Fassbinder and Soulary,[3] consisted in applying a sprayed coating to a steel tensile specimen and then fracturing the test piece. After fracture the specimen was examined and the distance from the fracture to the first cracks was found and also the distance from the fracture at which it ceased to be possible to remove the coating by scratching. Their results for several metals are shown in Table I.

Shear tests are very often called for, and some results obtained on 1-in. shafts are given in Table II.

TABLE II

Shafts threaded 30 to the inch; collars ¼ in. thickness, without notches.

Shear	Phosphor Bronze	2·9 tons/sq. in.
	Nickel	4·85 "
	Mild Steel	3·9 "
	18/8 Austenitic Steel	6·7 "
	0·85% Carbon Steel	7·1 "
	Zinc	0·56 "

These figures will show that the adhesion between the metal-sprayed coating and the basis metal can be remarkably high when the surface has been prepared in the correct way.

Bend tests have little significance in relation to the adhesion of sprayed coatings and yet they are often required. They may be of use where a job has to undergo considerable distortion after spraying, although, normally, spraying should be the last process of fabrication in order to avoid the necessity of bending. Generally speaking a steel sheet sprayed with under 0·004 in. thickness of metal can be bent through 180° without the coating cracking off. Above this thickness the coating will commence cracking when bent through angles less than 180°. Obviously, the angle of bending before cracking commences is dependent more upon the thickness of the sprayed coating than upon the intrinsic adherence of the deposit.

Hardness

Because of the porosity and oxide content of sprayed metal the hardness is different from that of the cast or

1 Greenwood, H. W., *Metallurgia*, 1947, **37**, 60.
2 Ballard, W. E., "Metal Spraying and Sprayed Metal" (Griffin & Co.), 1948.
3 Fassbinder, J., and Soulary, P., 12th Internat. Congr. Acet. Oxy-Acet. Welding and Allied Ind., 1936.

TABLE I

Metal* and Process	Breaking Load kg.	Distance to Cracks mm.	Stress at Cracks kg./sq.mm.	Scratching Limit mm.	Stress at Scratching Limit kg./sq.mm.	Remarks
ZW 1 ..	870	115	29	125	31	Partial adherence in cracked zone
ZW 2 ..	875	113	29	128	31	
ZW 3 ..	875	113	29	122	31	
ZP 2 ..	950	114	32	111	30	
AW 2 ..	950	97	32	109	32·5	
AP 2 ..	875				Coarse and whole deposit easily scraped off	
BW 2 ..	1,075	82	29	85	30	As ZW 1
CW 2 ..	975	99	26	105	28·5	"
SW ..	1,050	102	29	104	30	"

*Z Zinc. A Aluminium. P Powder Process.
B Brass. S 18/8 Stainless Steel. W Wire Process.
C Copper. 1, 2, 3 No. of layers 0·04mm.

TABLE III

Metal or Alloy	Cast Material	Sprayed Coating[1]	Sprayed Block Tested on Top	Sprayed Block Tested on Side
Scratch hardness tests :	(Width of scratch in mm.).			
Tin	0·08	0·056	0·055	0·055
Aluminium	0·06	0·044	0·048	0·05
Zinc	0·05	0·032	0·033	0·035
Copper	0·05	0·029	0·03	0·03
Iron	0·02	—	0·02	0·022
Brass	0·05	0·032	—	—
Bronze	0·023	0·025	—	—
Ball hardness tests :	(Diameter of indentation in mm.).			
Tin	>0·8	0·77	0·8	0·8
Aluminium	0·61	0·44	0·57	0·62
Zinc	0·44	0·42	0·55	0·57
Copper	0·54	0·38	0·42	0·54
Iron	0·32	—	0·33	0·38
Brass	0·54	0·43	—	—
Bronze	0·3	0·43	—	—
Scleroscope hardness figures				
Tin	5–6	—	11·5	11·0
Aluminium	6	—	12·0	10·0
Zinc	12	—	19·0	13·0
Copper	17	—	50·0	47·0
Iron	25	—	55·0	45·0

1 All coatings sprayed by wire process.

wrought metal. On the one hand porosity will cause a lower indentation hardness, whilst on the other the oxide content will cause a higher scratch hardness than the original metal in massive form. Factors which affect these two characteristics of sprayed metal will, therefore, cause a variation in the hardness of the deposit.

Results obtained by Turner[4] for scratch hardness, indentation tests and scleroscope hardness are given in Table III.

It is seen from these results that the scratch and scleroscope figures for sprayed metal are higher than for the cast metal, whereas the ball indentation figures show that the sprayed metal is probably slightly softer than the cast metal. Table IV[5] shows the Brinell hardness of sprayed metal blocks, and it is also interesting to record the effect of annealing on the hardness of sprayed metal in Table V[5].

TABLE IV

Lead	8·3	Nickel	195		
Tin	17·4*	Swedish iron	210		
Cadmium	27·5*	Mild Steel	320*		
Zinc	20·7	0·4% C. steel	275	Sprayed cold	
Aluminium	17·5	0·75% "	336		
70/30 Brass	89·7	0·90% "	550		
Copper	93·5	Stainless steel 18/8	301		
Phosphor Bronze	150·0	0·4% C. Steel	208	Sprayed hot	
Monel Metal	192	0·75% C. Steel	280		

* Sprayed metal deposited without any special precautions, and large amounts of oxide inclusions present.

Structure of Sprayed Metal

Sprayed metal is especially distinguished by its lamellar structure, and at a high magnification the contours of each individual particle can be identified. Upon hitting the surface of the object the spray particles are flattened out into a saucer shape, partly through impact and partly through surface tension forces. Each particle still preserves its identity in the deposit; there is no "crystal growth," or sintering process involved in the formation of a sprayed deposit. The particulate nature of the deposit coupled with the oxide content, porosity and mode of application all combine to give a structure to sprayed metal which is quite unique, presenting many useful features, but also giving rise to many problems.

Sprayed coatings are usually examined microscopically by viewing a cross section parallel to the direction of spraying. Fig. 1 is a typical example of good spraying and shows a coating of zinc sprayed by the wire process.

4 Turner, T. H., and Ballard, W. E., *J. Inst. Metals*, 1924, **32**, 291.
5 Metallisation, Ltd. (Ballard, W. E., "Metal Spraying and Sprayed Metal," p. 232).

TABLE V.—EFFECT OF ANNEALING ON HARDNESS OF SPRAYED STEEL (BALLARD)

Temperature of Treatment ° C.	Time of Treatment Minutes	Atmosphere of Furnace	Brinell Hardness
500	30	Hydrogen	372
500	30	Air	386
600	30	Hydrogen	352
600	30	Air	360
700	30	Hydrogen	318
700	30	Air	340
800	30	Hydrogen	221
800	30	Air	263
800	60	Hydrogen	148
800	60	Air	250
800	120	Hydrogen	120
800	120	Air	248

Carbon content of wire = 0·7%. Brinell hardness of deposit as sprayed 402.

The structures of deposits produced by the wire and molten metal processes are usually nearly indistinguishable, but the powder process yields a structure which is considerably different from the other two. In general we find with the powder process that the oxide content and porosity are higher thus giving rise to important structural differences. We can see this, for example, by comparing the photomicrographs of aluminium sprayed by the wire and powder processes. (Figs. 2 and 3). The reasons for this difference are not hard to find. In the first place the oxide content of the powder used for spraying will be much higher than that of wire, and secondly, there is little doubt that particles of unmelted powder are blown through the heating zone and become embedded in the matrix of the coating. With the wire process, of course, particles cannot be projected on to the surface of the object unless they have already been melted. Another factor contributing to increased oxide content and porosity of powder-sprayed deposits is the much larger distance between the pistol nozzle and the work to be sprayed coupled with the long, hot flame.

Investigations of the oxide content and porosity of the deposits produced by the various methods brings out still further the differences which microscopical examination seems to show. The porosity of sprayed deposits was found by Rollason[6] using a method of measuring the permeability to toluene. Some of his results are given in Table VI.

Rollason also investigated the oxide content of sprayed metals and found remarkably high values in some cases. The oxide content of an easily oxidised metal such as copper is immediately apparent by referring to Fig. 4 which shows a copper deposit sprayed by the wire process. The structure of sprayed copper is

6 Rollason, E. C., *J. Inst. Metals*, 1937, **60**, 35.

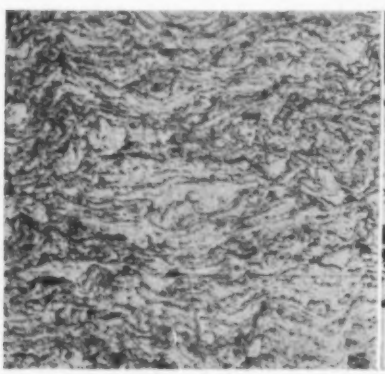


Fig. 1.—Sprayed zinc. Etched. × 175.

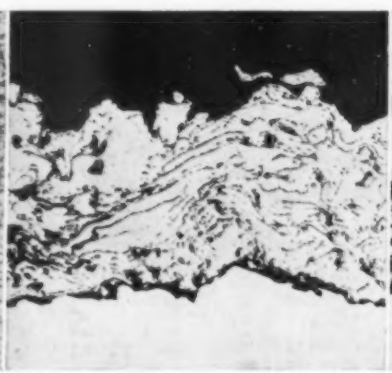


Fig. 2.—Aluminium sprayed by the wire process. Etched. × 175.

Fig. 3.—Aluminium sprayed by the powder process. Etched. × 175.

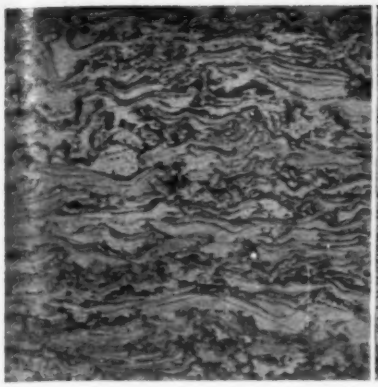


Fig. 4.—Sprayed copper. Etched. ×175.

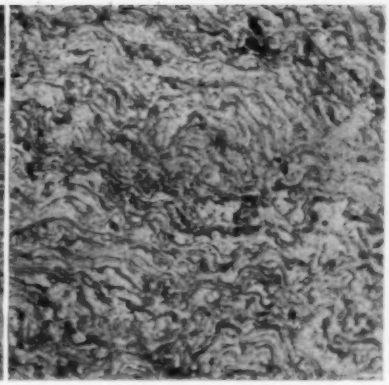


Fig. 5.—0·4%C. steel sprayed by the wire process. Etched. ×175.

TABLE VI

Process	Metal	Spraying Distance Inches	Porosity %
English wire	Zinc	3	3·9
,,	,,	5	4·5
,,	,,	7	6·6
Molten metal	,,	3	10·9
,,	,,	5	11·7
,,	,,	7	14·3
Powder	,,	8	13·8
,,	,,	12	18·4
American wire	Aluminium	Normal	12·8
Powder	,,	8	32·7
,,	,,	11	34·3
Molten metal	Aluminium-silicon	Normal	3·3
,,	Tin	,,	1·0
English wire	,,	3	6·8
,,	,,	5	7·0
,,	,,	7	7·9
,,	Copper	3	9·1
Powder	,,	8	21·4
,,	,,	10	22·8
American wire	,,	3	11·8
English wire	18/8	Normal	6·1
,,	0·7% C. Steel	,,	3·4
,,	Mild Steel	,,	2·3
,,	Lead	,,	4·6

beautifully brought out merely by polishing without any need for etching. Figures obtained by Rollason[6] for the oxide content of sprayed copper shows the great difference that it is possible to have between deposits produced by the various spraying procedures (Table VII).

TABLE VII

Type of Pistol	Nozzle Distance inches	Oxygen %	Cu_2O %
Powder Pistol	8	2·84	25·6
,, ,, ...	10	3·39	30·6
,, ,, ...	12	3·17	28·4
American Wire	3	1·72	15·4
English Wire	3 C.G.	1·02	9·2
,, ,, ...	3 Ac	0·59	5·3
French Wire	3 Ac	0·71	6·4

C.G. = Coal gas. Ac = Acetylene.

It can be seen, therefore, that when we are considering sprayed deposits we must take into account the particular properties afforded by the spraying procedure. We cannot treat a metal coated by spraying as a material clad with a sheet of rolled or cast metal. It is only by paying attention to the intrinsic properties of sprayed metal that the advantages of the process will be realised to the full. It is useless, for example, to attempt to ignore the porous nature of a sprayed deposit. Whilst a deposit of, say, 0·004–0·005 in. of any common metal is impermeable to liquids, the structure is definitely porous, and this porosity can be put to excellent use, a good example of this being in building-up work.

The reclaiming of worn parts by metal spraying offers distinct advantages over the two other well-known methods of welding and heavy electroplating. It may at first sight seem rather remarkable that worn crankshaft journals, pistons, shafts and the like can be successfully built up by applying a sprayed coating. Such jobs are, however, routine to the metal-spraying industry and the success of the method is greatly dependent upon the unique structure of the sprayed deposit. The preparation of the job before spraying is most important, and for details reference should be made to other work dealing especially with this.[2, 7] The very slight wear suffered by sprayed metal used, for example, to build up a crankshaft is due to the essential porosity of the deposit which retains a tenacious oil film giving rise to excellent lubrication. The wear on the surface will depend much more upon the conditions of lubrication than upon the surface hardness and hence arise the superior properties of sprayed metal.

A considerable amount of experimental work was carried out to demonstrate this point[8] and some of the results obtained may be summarised. In a series of oil "cut-off" tests it was found that whereas an ordinary hardened steel shaft running in white metal bearings seized in three hours after the oil supply had been cut off, a sprayed steel shaft ran for 22½ hours before seizing. Tests were further carried out on crankshafts fitted to private and commercial vehicles. Half of the journals on each crankshaft were reduced below size and built up by spraying steel, which after grinding to size had a thickness of about $\frac{1}{16}$ in. Private car engines, commercial vehicle engines engaged in journeys of 50 to 200 miles, and petrol and diesel-bus engines were all included in these tests. Checks were made on the wear on the journals after 1,000, 5,000, 10,000 and 15,000 miles and in no case was the wear on the sprayed journals found to exceed that on the ordinary journals. A thinner deposit of sprayed steel had no effect on the results. In the case of the private cars, commercial vehicles and petrol-bus engines the wear on the sprayed journals was about 15% less than on the ordinary journals, whilst with the diesel-bus engines the wear on the sprayed shafts was 50% less than on the ordinary journals. It was also a noticeable fact that the wear on the contacting bearings was noticeably less when sprayed journals were used and amounted to 40–55% less than with ordinary journals.

Obviously, therefore, with sprayed steel we are dealing with a material which has much better properties for this type of work than ordinary hardened steel. The structure of the sprayed steel deposit, upon which so much depends, is shown in Fig. 5, and the excellent film of lubricant held on the surface of this porous deposit can easily be visualised.

7 Ballard, W. E., "The Reclamation of Worn Parts by Metal Spraying," *Proc. Inst. Automobile Engineers*, **10**, No. 4, p. 77; Parkes, R. A., "Reclamation of Crankshafts," Assoc. of Metal Sprayers, October, 1943.

8 Shaw, H., "Metal-sprayed Bearings for High-speed Operation," Assoc. of Metal Sprayers, March, 1939.

The advantages of the porous structure of sprayed metal are not, of course, confined to steel deposits in building-up work but extend also to the field of corrosion protection. As has already been mentioned a coating of 0·004–0·005 in. of sprayed metal presents an impermeable barrier for corrosion protection, so that sprayed metal coatings do, in themselves, possess excellent anti-corrosion properties. It is, however, often desirable to finish off by painting and in these cases sprayed coatings provide an excellent "key" for the paint, and there seems to be no doubt that the system-sprayed coating plus finishing paint provides protection of an order achieved by few other protective systems. In the case of the protection of iron and steel this is doubly important, for not only is greater protection given, but the paint manufacturer can develop his painting schemes in the knowledge that a standard surface is provided. For structural steel work this will lead to the maximum life being obtained from each painting scheme, with correspondingly decreased costs as far as repainting is concerned, coupled with complete protection against corrosion.

Sprayed metal coatings as corrosion protectives have now come fully into their own in constructional engineering and they are replacing the older method of weathering, wire brushing and red-lead primer. An excellent example of this can be seen in the use of a 0·004 in. sprayed aluminium coating on a large proportion of the structural steel work at the Steel Company of Wales Works in process of erection at Margam.

There is no doubt, therefore, of the important service which metal spraying can render to the industrial economy in this country, as already pointed out by Mr. Greenwood. The purpose of this communication has not been, however, to show the various uses to which metal spraying can be put, but rather to ensure that users and would-be users of the metal-spraying technique shall know something of the product with which they are dealing. Sprayed metal offers a unique structure and unique properties, and it is only by a knowledge of these factors that modern industry can use it to the best advantage.

Acknowledgments

The author's thanks are due to the Directors of Metallisation, Ltd. for permission to publish the illustrations, and especially to Mr. W. E. Ballard (Managing Director) for assistance in the preparation of the paper.

Oxygen in Industry

THOSE who had the privilege of seeing the special showing of the new colour film produced by The British Oxygen Company, Ltd., would probably experience some surprise at the enormous increase in the uses of oxygen in industry which it portrays. The film commences with the discovery and isolation of oxygen (1770–74) by the German scientist Carl Wilhelm Scheele, and goes on to give the subsequent developments by Priestley, Lavoisier, de Richemont and Thomas Fletcher, who, in 1886, was the first to cut steel plate with a jet of oxygen. The film describes how these inventions and discoveries enabled Henri Louis le Chatelier to prove that the combustion of acetylene with oxygen produced a flame of a higher temperature than any previously attained. It shows how these experiments in the laboratories of British and European scientists have led to the growth of such large industrial organisations as the British Oxygen Company, Limited.

The modern method of liquid oxygen manufacture in the Company's works is shown and simply explained, together with the method of distributing the liquid oxygen in specially designed mobile tanks to large industrial users. There the liquid is transferred to special evaporating plant and the gaseous oxygen produced is conveyed by pipeline to points of usage. For consumers using smaller quantities of oxygen, the gas is compressed into high-pressure cylinders for distribution in the gaseous form.

Many illustrations of welding are given and these include the fabrication of stainless steel beer barrels and milk churns, hundreds of which can be turned out daily by a single welder; steel furniture for the home, for industry and for public use and even toys which are today subject to the welding process. Repair work is shown and this covers cracked cylinder-heads, broken aluminium aircraft cowlings as well as body-work repairs on motor vehicles. The joining of dissimilar metals is explained, such as bronze-welding cast-iron to steel, copper to steel, copper to brass, and a process for welding aluminium to steel. Small section light gauge aluminium parts are joined together by aluminium brazing—another new process of particular importance to the aircraft and automobile industries and to the fabrication trades generally.

Under-water cutting is shown in operation using the oxy-hydrogen blowpipe. As also are the oxygen-cutting of stainless steel and non-ferrous metals, a new process explained in the film; the deseaming process, introduced by The British Oxygen Company, Ltd., to Great Britain in 1936 for manually removing surface defects from semi-finished steel products, which has been widely adopted by the steel industry.

Defective welds are easily removed by 'Gouging', and welded structures are readily dismantled by this method in which the cutting action can be controlled to any desired depth. This process is shown in operation as also is the flame-cleaning process used for preparing iron and steel structures for painting by removing heavy rust and loose scale with a specially designed oxy-acetylene blowpipe. Flame-hardening of iron and steel by localised heating and quenching is demonstrated on gear wheels and forming blades for bending machines. Tubes are shown being formed by flame-spinning.

This colour film with its non-technical approach to a highly-technical subject will have widespread appeal; not only to those engaged in the metal industry but to many others who will find it has much of general interest. It is an educational film of high merit and the Company is to be congratulated on its production. Enquiries concerning this film should be made to The British Oxygen Company, Ltd., Grosvenor House, Park Lane, London, W.1.

AT the International Conference on Powder Metallurgy, held recently at Graz, Dr. W. D. Jones was awarded an Honorary Degree of Doctor of Technical Sciences in recognition of services rendered to the development of powder metallurgy.

Co-operative Research Activities

Reports of the Work of British Research Laboratories and Associations

While man, rather than matter, is the chief problem of the world, science applied to matter is greatly widening his horizons and increasing his knowledge of the world. Applying this knowledge is undoubtedly contributing to progress, but success necessitates persistent research in all phases of human activity. One of these phases is the subject of this article, which comprises a series of reports from Government sponsored research associations, outlining the work done, in progress or contemplated. It is an annual feature and the objective is to keep readers informed of the work being done within our field to assist the advancement of industries concerned.

SCIENCE has greatly widened our horizons and increased our knowledge. In the sciences are no vague and quibbling scholastism, no expressions of opinion without proof, but a sound and and logical system of expanding knowledge based on the intellect alone and freed from unintelligible mysticism. Here one deals with facts—measurable, quantitative, subject to critical and objective test. Science is based on matter and energy, on tangible and material things. It is deterministic and bows down to physical laws. It is the background of all research designed to establish ascendency over disease, increase food production, economise motive power, reduce limitations of products capable of being made from the materials of the world, and cheapen production.

Gradually the gulf that formerly existed between scientific knowledge and its application is being narrowed and to-day it is generally recognised that progress is dependent upon the ability to apply this knowledge to the problems of mankind. Application has led to remarkable discoveries, but development is usually gradual because persistent research is necessary to widen their scope. This is especially true in industry where advances are more readily applied in stages, economic considerations, however, persistently tend to quicken the application of the results of research that improve or cheapen production. For this purpose many manufacturers have set up their own laboratories not only to assist the production of better or cheaper products, but in developing new products and in improving production technique. While much industrial research is carried out by private firms, a number of co-operative research organisations, specially instituted to serve particular fields of activity, have been functioning for many years with increasing success. Each is supported partially or wholely by the Government. The following reports from several of these organisations outline some of the directions in which each is contributing to the advancement of the industry it serves.

Metallurgical Research at the National Physical Laboratory

Dr. N. P. Allen, M.Met.

Superintendant—Metallurgy Division, National Physical Laboratory

The salient features of the work of the Metallurgy Division of the National Physical Laboratory are outlined in this article. Reference is made to the use of phase contrast illumination in microscopy and to the replica technique for the examination of metallurgical specimens by the electron microscope. Work on the effect, on creep strength, of a precipitate in a soft matrix and on the appearance of sigma phase in iron-nickel-chromium alloys is described, and the possible future of the higher melting-point metals is discussed.

IN a laboratory such as the National Physical Laboratory there is always a proportion of routine work, which remains much the same from year to year, but, as time passes, the accent changes from one part of the work to another, and each year some interesting new subject arises.

At present the emphasis is on the national drive to increase exports. The National Physical Laboratory is not primarily a place where confidential government research is carried out, though work of that kind is always going on. Its main purpose is to assist the industries of the country in the application of scientific principles and methods to their work. It is one of the few laboratories to which a firm can turn for help when it is faced with a problem outside its normal experience, and this help may consist either of advice or of experimental work.

It is a matter for debate whether industry is best served by endeavouring to provide quick answers to the immediate questions of individuals or by carrying out exhaustive investigations of deeper problems which interest a group of industries. Probably there is room for both types of work ; but, for the present, and until the immediate economic danger is past, the policy of the Laboratory is to let the longer term theoretical problem yield place to the urgent practical one, and to offer as

much assistance to individual firms as can reasonably be provided. The enquiries that come in cover an extraordinarily wide range of articles, of which needles, boiler plates, lighter flints, electric cables and transformer sheets are a few—and give a vivid impression of the variety of special skills by means of which this country expects to maintain its commercial position.

Microscopy

Looking back at the account of the metallurgical work of the National Physical Laboratory that was given in this journal two years ago, it is interesting to note the very lukewarm reference that was made to the use of the electron microscope. Since then, much painstaking work has been carried out on the reliability of the transparent surface replicas that are used when metals are being examined, and considerable faith is now placed in them at magnifications up to 20,000 diameters. At present, the structures of heat-treated steels are being examined in detail and work is likely to be concentrated on this subject for some little time to come. The dark etching "sorbitic" and "troostitic" structures so well known to the ferrous metallographer are now being clearly resolved (Fig. 1), and though final conclusions have not yet been reached there is every hope that a better understanding of these structures will eventually be reached. Progress is also being made with aluminium alloys.

It should be remembered, however, that at best the replica reproduces only the shape of the polished and etched surface, and if its indications are to be relied upon, the polishing and etching must be performed with a skill appropriate to the high magnifications that are to be employed. Mechanical polishing can be surprisingly good for hard metals like steel: but for softer metals electrolytic polishing is more successful. For distinguishing the phases in an alloy, an etching reagent which uniformly dissolves some phases and leaves the others standing in relief is generally preferred. The parts in relief cause thin places to be present in the replica, and these show as bright patches in the electron micrograph (Fig. 1). The personal skill needed for making replicas is not so great that an intelligent young person cannot acquire it in the course of a few months, and since the present trend in the design of electron microscopes is to make them quicker and easier to operate, it should not be long before the electron microscope takes its place beside the optical microscope in the average metallurgical research laboratory.

During the course of the work on replicas, a phase contrast metallurgical microscope has been developed. It employs a modified method of illumination, which has the effect of revealing the differences of level in the etched microspecimen in the form of differences in tone of the image. Generally high spots in the specimen appear bright, and depressed areas dark. The effect, compared with that of normal vertical illumination, is shown in Fig. 2. This figure shows cementite particles in a matrix of ferrite in a quenched and tempered steel. The cementite has not been attacked by the etching reagent, and therefore stands out from the surrounding ferrite. It appears brilliantly white in the phase contrast photograph, against a background of dark ferrite, whereas in the photograph by normal vertical illumination the cementite particles are indicated only by a dark outline. The effect given by the phase contrast microscope

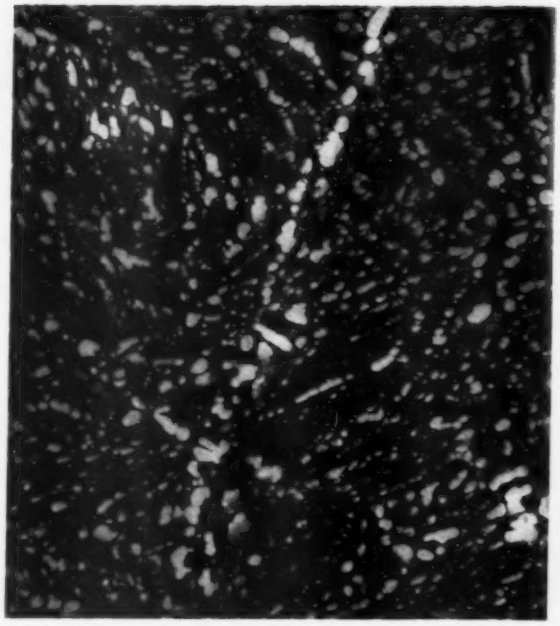


Fig. 1.—0.6% carbon steel quenched in water and tempered at 550° C. Etched in picric acid. × 10,000

can be very similar to that given by the electron microscope when a simple replica technique is used, as may be seen by comparing Fig. 1 with Fig. 2 (b). The phase contrast microscope can reveal very small differences of level. It will be noticed that in Fig. 2 detail of the ferrite is seen in the phase contrast photograph (2b) that cannot be found in the other (2a). It is expected that this feature will be particularly useful in studying the action of etching reagents. The phase contrast method of illumination can be applied to a conventional metallurgical microscope, and Fig. 3 shows the Vickers' microscope so adapted.

Creep

Work on the constitution of the iron-nickel-chromium alloys at the temperatures at which they are used as heat and creep-resisting alloys has made steady progress. Some of these alloys reach equilibrium very slowly indeed, and it may be years before a statement about their ultimate equilibrium can be made. A description of their behaviour in times of the order of six months will, however, be made available shortly. It has become very evident that the rate at which their constitution changes is strongly influenced by their initial conditions, and this may have an important bearing on the strength that the alloys exhibit at high temperatures. Annealed alloys change a great deal more slowly than cold-worked alloys, often more than a hundred times more slowly, and where a material has been only slighly deformed plastically, local alterations may be initiated, which might in some circumstances be a source of weakness, and in others a source of strength. Sigma phase is liable to appear in all pure iron-nickel-chromium alloys that contain over 20% of chromium, and it is clear that many popular heat-resisting alloys would be liable to contain some sigma phase after prolonged heating if they were pure. But ordinary commercial alloys are not as pure

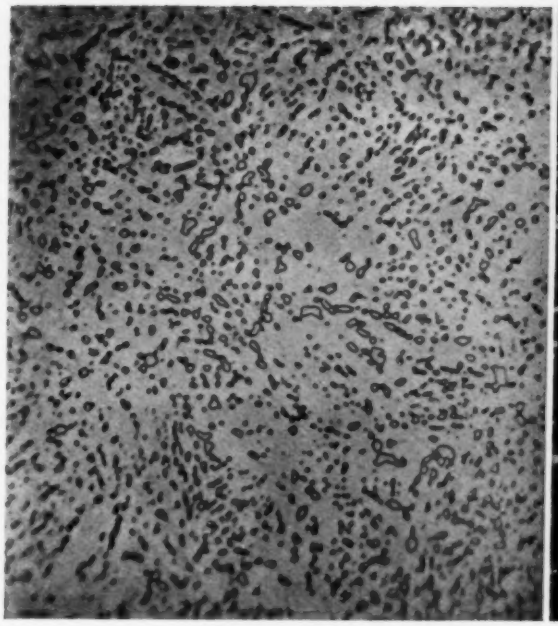


Fig. 2a.—Cementite in a matrix of ferrite. Normal illumination. × 1,500

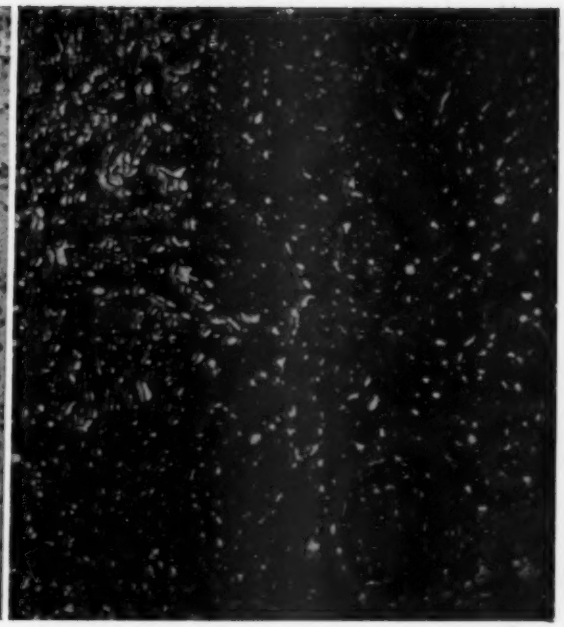


Fig. 2b.—Cementite in a matrix of ferrite. Phase contrast illumination. × 1,500

as the materials that have been examined at the National Physical Laboratory, and the effects of the quantities of carbon, nitrogen, silicon and manganese that are ordinarily present remain to be determined. The quantity of sigma phase, and the form in which it appears, varies widely in different alloys. At present there is very little published systematic information on the effect of these factors on the engineering properties of the alloys. This is a matter on which we cannot afford to remain ignorant, and on which systematic work will eventually have to be done. Meanwhile, although there is ample evidence that the sigma phase in the mass is brittle, it is necessary to avoid drawing the conclusion that any alloy which contains a proportion of sigma phase is necessarily useless. Alloys with finely dispersed sigma phase may, for all that is known at present, show very desirable characteristics, and the cautious student will maintain an open mind until evidence is available.

The effect on creep strength of a precipitate in a soft matrix is being studied in the magnesium cerium alloys. Cerium is well known to increase the creep resistance of magnesium alloys, and the effect of the studies being made at the National Physical Laboratory is to suggest that the greater part of the increase in strength is due to the limited proportion of cerium (about 1½%) which can be taken into solid solution at temperatures near the melting point. This cerium is, naturally, available for precipitation at lower temperatures. In this case the greatest creep resistance appears to correspond to a stage at which no clearly defined precipitate can be detected with the optical microscope. When a resolvable precipitate is present, the creep resistance is low. The electron microscope has not yet been applied to this problem and it will be interesting, in due course, to see whether any trace of a precipitate can be found when the alloy is in its most creep-resistant condition. Similar studies are being made of the effect of precipitates from solid solution on the high-temperature strength of aluminium alloys, in the hope that the general conditions associated with creep resistance at high temperatures will be revealed.

High Melting Point Metals

Aluminium and magnesium are chosen for these studies because they are easy to handle in the laboratory. The future of really strong, high-temperature creep-resisting alloys will lie in practice with metals of much higher melting point, whose metallurgical handling will no doubt present many difficulties. With this situation in mind, attention has recently been directed to the metallography and properties of a number of metals with melting points higher than that of iron. Titanium and zirconium, in spite of their high-melting points, turn out to be disappointingly weak at the sort of temperature which is now being considered in gas turbine and jet engines. This remark refers to the moderately pure metals; it is perhaps early yet to say what alloying might bring forth. Platinum and the platinum metals, so far as they have been studied, show little advantage over the metals of the iron group, which are already very fully exploited. The best chances of exceptional strength at high temperatures appear to lie in the metals of Group Va and VIa, and all these metals possess a troublesome degree of chemical activity at high temperatures. During the past year, a laboratory has been set up for examining the chemical equilibria into which these metals enter at high temperature, and the data that will be obtained should throw considerable light on the ways in which their chemical behaviour can best be controlled. At the moment titanium and vanadium are being looked into.

Many metals of high melting point (vanadium is one) dissolve in the solid state appreciable amounts of their

own oxides, which modify their properties very considerably. The exact determination and control of the oxygen contents is thus an important feature of their metallurgy. Fortunately the vacuum-fusion method of analysis appears to be adequate in most cases, and a considerable amount of attention is being given to the details of procedure.

It has been said that titanium is unlikely to be suitable for the high-temperature creep-resisting alloy field, but for other applications it has attractive properties. Although it cannot yet be said to have arrived as a large-scale industrial metal, it is plainly knocking at the door, in the same way as aluminium was knocking at the door 60 years ago, and it must be taken notice of. He would be a bold prophet who would say either that it will grow rapidly in importance as aluminium has done, or that it will struggle ineffectively against a variety of technical and economic difficulties, but the present indications are that interest is increasing at a sufficient pace to justify an examination of its metallography. For this reason more attention is now being given to titanium at the National Physical Laboratory than has previously been the case.

Amongst older subjects of research, it may be mentioned that progress has been made in the vacuum melting of pure iron on a scale larger than has previously been attempted, and that the Izod impact value of iron of a high standard of purity has been found to be extraordinarily sensitive to minor details in the method of preparation. A good deal of attention has recently been given to the welding properties of magnesium alloyed with 4–7% of aluminium as compared with those of other magnesium-rich alloys. This work has been done in co-operation with the British Welding Research Association, and its general tenor is to show that the simple magnesium-aluminium alloys have a combination of properties which is worthy of attention. The rolling of these alloys, particularly when they are made of high-purity materials, is not so formidable as it has often been assumed to be, and very thin sheets have recently been produced quite successfully. Recent X-ray studies of hardened gauge steels have shown that by sufficiently detailed measurement of line breadths, useful information can be obtained about the low-temperature stabilisation treatments that have been carried out. These and many other subjects are not yet ripe for discussion but should develop in interest as their details are progressively worked out.

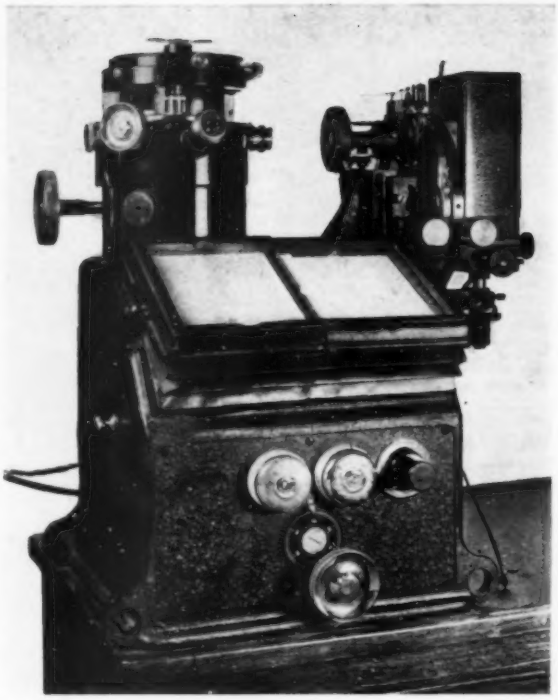


Fig. 3.—Vickers' microscope adapted for use with phase contrast illumination. The phase contrast illuminator is shown on the right and is used in conjunction with a special phase contrast objective substituted for the normal objective.

British Iron and Steel Research Association

Several examples of the results which can be achieved by the close co-operation of an industry and its research association are provided by this survey of the British Iron and Steel Research Association's activities during the past year. Although the laboratory side of the work is adequately provided for, or will be, when the building programme is completed, it will be noted that much of the work of the Association's six divisions is conducted in the works of its members.

STEADY progress in the practical application of scientific knowledge has been the keynote of the last twelve months at B.I.S.R.A. In September, 1947, METALLURGIA described the methods and facilities with which the Association works, and there have been two major developments since then. In October, 1947, the Associations' Physics Laboratories were officially opened in Battersea by the late Lord Rayleigh (METALLURGIA, November, 1947) and in the early months of this year a start was made on the construction of a Metal Flow Research Station at a site in Sheffield. Licences for the construction of only 5,000 sq. ft. of space have so far been obtained, and here it is intended to centralise wire drawing and instrument laboratories, a machine shop and a number of offices. It is hoped to start moving equipment into the temporary premises during the autumn of 1948, but it is not yet known when it is likely that work on the larger, permanent laboratory will be begun.

Among the most immediate projects of the Association are those involving the addition of oxygen to the air used in iron and steelmaking. This is a subject which

has recently become of increased importance as the production of "tonnage" oxygen at reasonable cost becomes a practical possibility. It lends itself to theoretical treatment in advance of practical work, and operational research on its possibilities has necessarily preceded application. Successful oxygen enrichment, however, has already been operated by B.I.S.R.A. and works' staff in routine production at a steel foundry in Leeds as described in METALLURGIA for August, 1948.

Steel Castings Division

This has been one of the projects of the Steel Castings Division of the Association. This Division is also concerned with bringing to the attention of industry the results in two other important fields of investigation. The first is that of the non-destructive testing of steel castings, and the second concerns core bonding agents. In each case a conference is being organised for the Autumn of 1948; September 8th and 9th for the former and October 21st and 22nd for the latter. Both conferences will be duly reported in METALLURGIA.

The aspects of non-destructive testing which are to be discussed are X-ray, Gamma ray, magnetic and ultrasonic methods and materials and, of course, acceptance standards. Considerable advances have been made in these fields of late, and this conference is being organised with the support of the Institute of Physics.

The object of the second conference is to bring to the notice of founders the wealth of information that has been obtained in recent years on the new materials that may be used for the bonding of foundry cores. The use of such materials, in many cases with an appreciable reduction in cost, would enable the linseed oil, used hitherto, to be diverted to alleviate the shortage of edible fats.

The Steel Castings Division is one of six more or less autonomous Divisions into which B.I.S.R.A., roughly parallelling the iron and steel industry itself, is divided. There are also several Departments which carry out fundamental research and other work common to several Divisions. A comprehensive report on the work of each would not be possible within the bounds of this article. The general nature of each Division's work is therefore indicated in what follows by the selection of one or two typical examples from among its projects.

Ironmaking Division

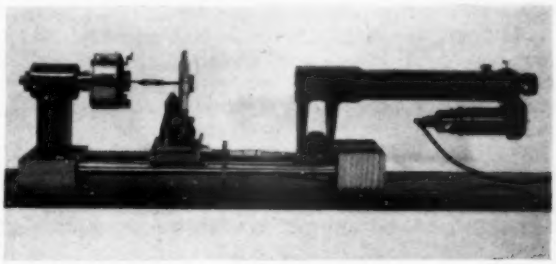
In present economic circumstances this Division naturally has an important preoccupation with means of immediately increasing pig iron output. High top pressure operation of blast furnaces is one such possibility and a statistical and theoretical analysis of extensive reports on such operation abroad has been made and circulated. Similarly, the possibilities of the use of oxygen-enriched blast are being examined, particularly with a view to its adoption in ferro-alloy furnaces.

Work on the crushing and screening characteristics of foreign ores has been carried out using various types of normal works equipment. The mode of breakdown and the proportion of fines in the product has been found to depend on the type of crusher employed as well as on the mineralogical constitution of the ore. Laboratory work concerned with reducibility raises the possibility of the formulation of a scale of sizes for different ores to be related to a selected standard of reducibility, which would be of considerable value to blast furnace operators using mixtures of ores. Laboratory and works trials directed to the improvement of sinter quality continue, and the optimum processing conditions and properties of a large range of sinters have been determined.

B.I.S.R.A's experimental blast furnace at the works of the Shelton Iron Steel and Coal Company is being used for work on temperature distribution and gas composition within the furnace, as is the ten-point sampling probe installed on a production furnace in the works of a member firm.

Steelmaking Division

This Division also has an experimental furnace at the works of the Shelton Iron Steel and Coal Company, in this case an open hearth. A modified Merz port was tried out here and gave excellent results before being installed on a 70-ton O.H. furnace at Messrs. Steel Peech and Tozer's works, where results have also been promising.



Wire-drawing die profilometer, designed and made in the B.I.S.R.A. physics laboratories. Plots of die profiles, accurate to 0·00001 in. on bore diameters of 0·03 in. and upwards, are obtainable by its use.

The instrumentation of O.H. furnaces provides an important field of work for this Division, and the O.H. Instuments Sub-Committee has undertaken the formulation of a handbook of instrument practice. The operation of automatic control units installed at several works, where the fuel rate is linked to the roof temperature, is being studied, both on oil- and gas-fired furnaces. In this connection the development by B.I.S.R.A's Physics Department of an electrical remote-indicating roof pressure meter is of interest. This instrument which was shown at the Physical Society's Exhibition in April, 1948, is capable of working over a range of pressures of $\pm 0{\cdot}1$ in. w.g., and by means of a null-balance system of measurement and by electrical transmission evades the "stack" effect in the pressure pipe from which normal measuring systems are apt to suffer.

The other projects of this Division range throughout its field from the use of oxygen and compressed air in open hearths and Bessemer converters to field trials on the performance of ingot moulds. In this last connection it is hoped to try in ingot mould manufacture the "nodular iron" developed by the B.C.I.R.A.

Mechanical Working Division

During the past year, B.I.S.R.A's rolling team has been studying the effects of front and back tension on cold rolled strip on the Association's 10-in. two-high mill in the University of Sheffield. The results of earlier work on rolling without tension and a description

of a new simplified method for calculating roll force and torque were reported to the Institution of Mechanical Engineers* in April of this year.

Back pull of reactive wire drawing has been the main subject of wire drawing research during this period. The work, now concluded, has been carried out on a Marshall Richards prototype backpull machine installed at Arthur Lee and Son's works in Sheffield. Trials have been made of the effects of backpull on die wear, maximum speed of drawing, the properties of the drawn wire and other factors. Die wear is also being comprehensively studied, with particular regard to the phenomenon of "ringing" at the entry of the die.

At the Association's South Wales Laboratories, a study of porosity in tinplate is one of the projects, and the Kerr test, after examination, has been used to compare the porosity of hot dipped and electrolytically applied tinplate coatings over a wide range of coating weights.

A method for measuring surface roughness by means of a replica technique used in conjunction with a stylus profilometer has been described in the Journal of the Iron and Steel Institute.† This is especially useful for dealing with relatively inaccessible surfaces such as those rolls which cannot be examined directly by instruments of the stylus profilometer type.

The construction of an experimental galvanising machine has recently been completed and with this it is intended to study the effects of the addition of different elements to the galvanising bath on adhesion, uniformity, spangle, etc.

Plant Engineering

Centralised engineering research calls for careful planning in the steel industry, where it is a comparative newcomer. The main emphasis in the programme is on the investigation of engineering problems on a broad basis, and on the establishment of the best engineering principles for application to the varying practice in the industry.

Such work is obviously of value in the execution of the steel development plan, and an example can be taken from an investigation of open hearth furnace charging. Here an attempt has been made by time studies in a number of melting shops to distinguish the limiting factors in time of charging. This involves consideration of the methods of conveying the materials to the melting shop stage and of the capacities of the furnaces and charging gear. The object has been to calculate the effect on these factors of projected methods of supplying materials. A detailed and quantitative basis of design and operation of such systems has already been used in connection with the planning of two new melting shops.

From the large number of other projects that this Division is engaged upon mention may be made of the continuing attempt to design (in consultation with the plant manufacturers) a radial burden distributing mechanism suitable for application to an existing modern blast furnace; time studies of ingot movements from teeming to mill racks; analyses of mill furnace practice and, on a larger scale altogether, a survey of the layout of integrated British steelworks, with a comparative study of the flow of materials.

* "Researches into the Deformation of Metals by Cold Rolling" and "Calculation of Roll Force and Torque in Cold Strip Rolling with Tensions," *Proceedings of the Institution of Mechanical Engineers*, April, 1948.

† *J.I.S.I.*, May, 1948, pp. 67-70.

Metallurgy Division

When the work of this Division was commented on in METALLURGIA for September, 1947, work on the brittle fracture of mild steel plates was described. Three papers on this subject were subsequently discussed at the Autumn meeting of the Iron and Steel Institute, and the practical side of this programme is now satisfactorily concluded. The long-term fundamental questions involved are still being pursued, though investigation is hampered by difficulties in manufacturing pure iron.

Work sponsored at Leeds University by this Division on overheating of steels has also had practical results, and may be regarded as complete. A steel susceptible to overheating may now be identified by a simple metallographic test, which also distinguishes between degrees of overheating and heating to incipient fusion. In addition, a heat treatment has been developed to correct the overheated condition.

The valuable work of the Standard Methods of Analysis Sub-Committee of the Iron and Steel Institute was taken over by B.I.S.R.A. on its formation and provides another example of practical work. In addition to the three methods published in B.S. 1121 by the former sub-committee, a further nine have been added and six more have been submitted for consideration. The very great amount of co-operative and detailed work that goes into these standard methods is a measure of their value both to steel manufacturer and steel user.

This Division has over 100 projects in hand, including a large number concerned with corrosion*. There are many other fields in which extensive work is being carried out, such as those of alloy steels, heat treatment and metal physics. In the last-named studies of, and with, micro-radiography and electron and other methods of microscopy, afford particular examples.

* METALLURGIA, June, 1948, pp. 104-106.

Zirconium Hydride

READERS will be interested to know that Murex, Ltd., is now producing zirconium hydride.

This is a product which previously had to be imported from the United States, but Murex, Ltd. now hope to be able to satisfy the domestic demand for this material. It is made in powder form, and contains about 98% Zr, the balance being mainly hydrogen.

Mr. R. B. Paul

MR. ROBERT BUCHANAN PAUL, M.C., A.M.I.E.E., who was overseas manager of British Insulated Callender's Cables, Ltd., died on August 9th at Weybridge, Surrey. His early electrical training was with Mavor & Coulson, Ltd., of Glasgow; he joined the outside contract staff of British Insulated & Helsby Cables, Ltd., prior to the first world war. During that war he served in the South Lancashire Regiment, rose to the rank of Captain and was awarded the M.C. Rejoining the company after that war, he went to India to become manager for India of British Insulated Cables, Ltd. On returning to England he was made agency manager and personal assistant to the general manager. Later, Mr. Paul became sales manager of British Insulated Cables, Ltd., and when the merger with Callender's Cable & Construction Co., Ltd., took place in 1945 he was appointed assistant overseas manager of British Insulated Callender's Cables, Ltd., and then finally overseas manager.

The British Cast Iron Research Association

By J. G. Pearce, M.Sc., M.I.Mech.E.,. M.I.E.E.

Director of Research

In this report of the work of the British Cast Iron Research Association reference is made to the nodular cast irons, which are the outcome of a comprehensive programme of research on the mechanism of graphite formation. Mention is also made of other work in progress, or completed, in the Association's laboratories during the past year, as well as to the educational activities in which the Association is interested.

REFERENCE was made in the last annual review of the work of the British Cast Iron Research Association (METALLURGIA, September, 1947) to the development of nodular graphite structures in cast iron in the as-cast state. Since that date a full description of the process whereby these structures may be obtained has been published[1, 2, 3] and a large quantity of data has been collected on the mechanical and physical properties of the new material.

Nodular Cast Iron

Briefly, the change in structure is effected by the addition of a small amount of cerium to a hematite-type iron, that is, a cast iron low in sulphur and high in carbon. Cerium has a strong affinity for oxygen and when added to molten cast iron it exerts a pronounced desulphurizing and carbide-stabilizing effect. It is usually added in the form of *Mischmetal*, an alloy containing 45-55% cerium, the addition being made in this form because of its ready availability. In a form of the process favoured by the Association, the metal is treated subsequent to the cerium addition with a ladle graphitising agent, such as ferro-silicon or silicon-manganese-zirconium. The sulphur content of the molten metal must be as low as possible and it is not practicable to treat metal with a sulphur content in excess of 0·06%. When necessary, the molten metal may be subjected to a preliminary desulphurising treatment, and this will probably be a necessity when producing the material in the cupola.[4] The iron to be treated must solidify grey in the untreated condition: the process cannot be applied to a white iron. With this reservation, the matrix structure may be pearlitic, ferritic, a mixture of ferrite and pearlite, martensitic, acicular or austenitic. A high carbon content is necessary and the iron to be treated should preferably be hypereutectic. The silicon content must be in excess of 2.3% and may be as high as 7% without influencing the essential features of the process. The phosphorus content should preferably be below 0·1% and should not exceed 0·5% since phosphorus contents in excess of the latter figure prevent the operation of the process.

It will be seen that the process is at present only applicable to the hematite types of iron. There are many important castings, however, particularly in the engineering industry, to which the process may be applied, since such castings are already made from low phosphorus material, and in general it may be said that all grey iron castings used for automobile production are suitable for treatment as well as other engineering castings.

Extensive tests have been carried out on the new material.[5] Transverse rupture stress varied from 40 tons per sq. in. on a 1·6 in. bar, to 64 tons per sq. in. on a 0·875 in. bar, for the single treated material. These strengths were considerably higher for the double treated material (i.e., treated with the cerium addition and a ladle graphitiser) and in a lower silicon material containing 1·5% copper, transverse stresses of over 80 tons per sq. in. were recorded. The low elastic deflections on nodular irons give high moduli of 18-26 $\times$ 10^6 lb. per sq. in., compared with an average figure of about 16-18 $\times$ 10^6 lb. per sq. in. for a high strength flake graphite acicular cast iron.

Tensile strengths ranged from 23 tons per sq. in. for the single treated materials to a range of 34·2 to 38·6 tons per sq. in. for the copper-containing double-treated irons with correspondingly high elastic moduli up to 24·4 $\times$ 10^6 lb. per sq. in. The ratio of transverse to tensile stress varies from 1·7 to 2·5. Brinell hardness numbers of nodular cast irons tend to be slightly higher than those of untreated material of otherwise similar analysis. Impact strengths were obtained up to 120 ft.lb., and the lowest figure obtained, 32 ft.lb., is as high as the figure for most high duty acicular irons. As might be expected, the damping capacity of nodular cast irons is lower than that of a flake graphite cast iron, but higher than that of a steel.

Nodular irons possess mechanical properties which might render the material particularly suitable for engineering applications where high strength and shock resistance, together with good machinability, are required. By heat-treatment or by the use of special alloying elements the mechanical properties of the material can be raised to a very high level. No less than nine papers dealing with this subject have appeared since March, 1947, in the form of contributions to leading technical institutions and a review of these has recently been published[6].

The use of cerium in this process has involved an experimental investigation into methods for the determination of cerium in cast iron for control purposes and a method of analysis has been satisfactorily developed by members of the Association's chemical research staff.[7]

A new method has also been effected for the direct colorimetric determination of tungsten in cast iron.[8]

This development of nodular structures in the as-cast state has emerged during research into the mechanism

1 Morrogh, H. and Williams, W. J. *Journal of the Iron and Steel Institute*, 1948, v. 158, March, pp. 306-322.
2 Pearce, J. G. Paper read at a meeting of the Chemical Engineering Group, 1948, Society of Chemical Industry, April 6th, Proof Copy, 5 pp.
3 Morrogh, H. American Foundrymen's Association, Annual Meeting, May, 1948. Preprint No. 48-46.
4 Dickinson, E. C. *Foundry Trade Journal*, 1948, v. 84, April 8, pp. 341-344.
5 Morrogh, H. and Grant, J. W. Institute of British Foundrymen, Annual Meeting, June, 1948, Paper No. 889, 22 pp.
6 Woodward, G. E. *B.C.I.R.A. Bulletin*, 1948, v. 9, July, pp. 200-204.
7 Westwood, W. and Mayer, A. *Analyst*, 1948, v. 73, May, pp. 275-282.
8 Westwood, W. and Mayer, A. *Analyst*, 1947, v. 72, November, pp. 464-469.

of graphite formation in cast iron and other investigations associated with this programme, pursued during the year under review. The latter include a study of solidification in the ternary iron-carbon-phosphorus system and the rate of graphitisation and nodule number of malleable cast irons. Work has also been begun upon slag/metal reactions and preliminary investigations will deal with the electrical properties of slags and the effect upon microstructure of melting under slags of various compositions. The contributions made by the chemical research staff towards perfecting new methods for the determination of small amounts of the rarer elements in cast iron is referred to elsewhere in this article, but in addition it may be mentioned that a comprehensive book on the chemical analysis of cast iron is now in the press, which will, it is expected, form the standard reference work on the subject. The application and extension of spectrochemical methods to the analysis of cast iron continue to be studied.

Other Work

Other work completed during the year, or still in progress, includes :—

1. Shrinkage and porosity in grey cast iron with special reference to the influence of fluidity.
2. Corrosion of cast iron. An investigation has been carried out during the year on the cavitation of cast-iron propellers in conjunction with the British Shipbuilding Research Association.
3. Mechanical properties of cast iron.
   (*a*) Nodular cast iron.
   (*b*) Stress/strain curves for ingot mould materials at elevated temperatures.
   (*c*) Mechanical properties of ring sections compared with those of corresponding round test bars.
   (*d*) Mechanical properties of cast iron at sub-zero temperatures.
   (*e*) Internal stress in iron castings. The preliminary work consists of a study of the mechanism and rate of relaxation of artificially applied stresses at elevated temperatures.
   (*f*) Influence of section size and shape on the transverse properties of cast-iron beams.
4. The effect of gases in cast iron with reference to the various factors which influence gas content and the determination of gases in cast iron.
5. Influence of composition, microstructure and design on resistance to thermal shock.
6. Relationship between the carbon equivalent value and the mechanical strength of ordinary grey cast irons.
7. Welding of cast iron.
8. Experimental work on moulding sands in connection with the formation of scabs, rust-spotting in light castings ; the utilization of synthetic resins as core-binders and the use of pitch powder in moulding sands.

The difficulties created by present shortages of raw materials in the foundry, and the question of possible substitutes especially in connection with bonding materials for cores and moulds, are under constant consideration.

The number of installations of the balanced blast cupola, developed by the Association a number of years ago, and now well established in the industry, is 343, with an aggregate hourly capacity of 2,640 tons. The present day variations in the quality of foundry coke are being closely followed in view of their significant influence on fuel economy in the ironfoundry.

In the course of recent work at the Association (reported in a paper to the Iron and Steel Institute[9]) a study was made of the carbide phase occurring in rapidly cooled cast irons containing up to about 7% silicon, with the object of establishing the validity of a claim originally made by Stead in 1910. Stead suggested that silicon present in white cast irons formed a silico-carbide less stable than normal iron-carbide (cementite) and he also demonstrated that the two carbides could occur together in a particular iron. Stead's claim is largely substantiated by this new investigation. It has been shown that with silicon contents between 2·5% and 7% a carbide phase, probably iron-silicon-carbide, co-exists with the iron carbide. Below 2·5% silicon, the carbide appears to consist entirely of cementite, while at about 7% silicon the carbide areas consist entirely of this presumed silico-carbide of iron.

Further contributions to the Iron and Steel Institute by the Association consist of a review of the results of an investigation into the causes of the peeling of whiteheart malleable cast iron[10] included in a symposium on this subject, and a paper on the annealing of white cast irons in hydrogen atmospheres.[11]

The Fourth Report of the Research Committee on High Duty Cast Irons for General Engineering Purposes (Institution of Mechanical Engineers) was recently issued[12] and summarises the mechanical properties of the acicular cast irons. The experimental work on which this report is based was carried out in the Association's laboratories.

An indication of the general improvement of the status of cast iron as an engineering material is to be found in the revised British Standard Specification (B.S. 1452, 1948) for grey iron castings, under which seven grades may now be specified with tensile strengths ranging from 10-26 tons per sq. in. on a 1·0 in. bar. The Association actively co-operated in the preparation of this specification, which shows a remarkable advance in the mechanical strengths nowadays to be expected from cast iron on those specified in the first British Standard (B.S. 321, 1928) issued for iron castings.

Education

During the year under review the Association held its first post-war Refresher Course at Ashorne Hill, near Leamington Spa, by courtesy of the British Iron and Steel Federation, in April, 1948. More than 20 lectures were given by members of the staff and by external lecturers. The course was attended by more than 200 delegates from member firms, together with students of the National Foundry College, and was a great success in every respect. Consideration is being given to the organisation of future conferences to be devoted to specific subjects and special aspects of foundry work.

The first session of the National Foundry College at Wolverhampton, in which the Association takes an active interest, was inaugurated in January, 1948. The new session will begin at Wolverhampton Technical College in September, 1948, and in the light of experience gained during the present session certain changes have

9 Marles, D. *Journal of the Iron and Steel Institute*, 1948, v. 158, April, pp. 433-436.
10 Bernstein, J. *Journal of the Iron and Steel Institute*, 1948, v. 158, January, pp. 20-36.
11 Bernstein, J. *Journal of the Iron and Steel Institute*, 1948, v. 159, May, pp. 11-15.
12 Pearce, J. G. Fourth Report of the Research Committee on High Duty Cast Irons for General Engineering Purposes : Acicular Cast Irons. Institution of Mechanical Engineers, Advance Copy, 8 pp.

been made in the curriculum. Experience has shown that some candidates require further preparation before being admitted to the final course, and for such students a preliminary course of six months duration, known as Part 1 of the Diploma Course, will be arranged to begin in January, 1949. The present Diploma Course will now be known as Part 2, and will begin on 27th September, 1948, and will be open to those students who are eligible by reason of their qualifications and previous training. In future sessions, both parts of the course will begin in September and will run concurrently, and the interval between the termination of Part 1 and the commencement of Part 2 of the course, may be usefully employed by the student in acquiring the requisite foundry experience.

The British Ceramic Research Association

By A. E. Dodd, M.Sc., A.R.I.C.
Head of the Information Department

The past year has seen the formation of the British Ceramic Research Association by the union of the British Refractories Research Association with the British Pottery Research Association. The raw materials and manufacturing methods of these two branches of the ceramic industry are closely related and both should reap the benefit of this combined attack on their common problems. An outline is given of some of the fields in which the new Association's activities will be pursued.

THE relationship between the several branches of the ceramic industry is perhaps even closer than that between the branches of the metallurgical industry; it may be said that, from some standpoints, the process of extracting copper from its ore differs from the smelting of iron more fundamentally than does the process of making fine china from that of making a common brick.

This community of interests has long been recognised by the technical society of the ceramic industry—The British Ceramic Society. Founded in 1900 to serve only the manufacturers of pottery, the council later acknowledged the wider interests of its members and in 1917 a section was formed to meet the needs of the refractory materials industry; in 1928 a third section was founded to serve the makers of clay building materials. For the past twenty years, therefore, the unity of the ceramic industries has been recognised by their technical society.

In the field of organised research the process of development has followed a different course. At the North Staffordshire Technical College, the late Dr. J. W. Mellor carried out important experimental work in the Pottery Department, of which he was Principal. During the first World War he also organised research on refractory materials, and in 1920 the British Refractories Research Association was founded with Dr. Mellor as Director.

The spirit of scientific inquiry has always been present within the industry; mention need be made only of the names of Josiah Wedgwood, Josiah Spode, and William Adams, to name but a few of the more prominently progressive men in the early days of the pottery industry. When, in 1904, the late Dr. Mellor began his long association with the industry this spirit of inquiry was quickened. The last twenty-five years have seen a steady growth towards a comprehensive study of ceramic technology, and in 1937 the British Pottery Research Association was formed to focus general basic research on pottery in a single well-equipped laboratory.

The third major group in the ceramic industry—the heavy clay section—has always been associated, through the membership of a considerable number of individual firms, with the B.R.R.A. During the second World War the Ministry of Works made increasing use of the research association for a technological survey of the heavy clay industry, and in the last two years liaison with this industry has been completed.

When the previous review of the current work of the B.R.R.A. was published in METALLURGIA a year ago, research on problems relating to refractory materials and heavy clay products was being handled by the B.R.R.A. and research on pottery was being carried out by the B.P.R.A., although a move had already been made to fuse the two associations. This move has come to full fruition in the present year, and the two older organisations have been merged into a single body—The British Ceramic Research Association, with Mr. A. T. Green, O.B.E., as the first Director of Research.

The chief justification for a comprehensive research association is the community of interests of the industries concerned: clay is the main raw material of all branches of the industry, and each has the same fundamental technology. The clay resources of the country have already been broadly examined by the Geological Survey, but a more detailed survey is now required after the manner in which the Fuel Research Station has dealt with the coal seams of the country. An improved series of tests for raw clays must be developed to make possible a fuller control of their properties. This obviously involves a considerable scientific exploration, and work is now well advanced on a survey of the physical properties of the clays of Great Britain; the research includes a study of particle size, plastic properties, drying and firing behaviour.

These physical properties of clay are controlled to some extent by the mineralogical constitution. The clay minerals can be classified in three groups: the kaolinite, montmorillonite, and illite groups. It has been found that the plasticity and bond strength of the clay minerals increases in the order kaolinite, illite and montmorillonite; the montmorillonite minerals, even when present in comparatively small amounts, give plasticity and strength to many clays, but owing to their high base-exchange capacities, the properties of unfired montmorillonite clays are peculiarly dependent on the nature of the adsorbed ions. It is recognised that research in this field is of interest not only to all branches of the ceramic industry, but also in the foundry where the properties of moulding sands and core sands require careful control.

Other research common to all sections of the industry includes the study of the design and efficiency of dryers and kilns. Experience gained in the operation of a tunnel kiln used in the firing of electrical porcelain, for example, may be of direct application in the design of a kiln for firing refractories. Operational research carried out on the works is also of high value in associating problems of a similar type.

A wide range of fundamental work needs to be carried out on reactions in the solid state and on the theory of sintering and melting. This field of physical chemistry is of importance to all process industries operating at high temperatures; taken together, the theory of the flow of powders under pressure and the surface melting of powders at points of contact form not only the basis of the dry-press method of shaping special refractories, certain types of electrical porcelain and wall tiles, but also of powder metallurgy. The study of the properties of refractory oxides is also of joint interest to the refractories, electrical porcelain and certain branches of the metal industries.

Perhaps sufficient has now been written to show that the vesting of ceramic research in a single Association will bring together much experimental effort and experience that would otherwise have been dispersed and duplicated. The wider resources of the British Ceramic Research Association should enable it to serve the metallurgical and other industries more effectively.

The British Welding Research Association

By F. A. Fox, D.Sc., F.I.M.

Deputy Director of Research

The widespread adoption of welding methods in the fabrication of ferrous and non-ferrous metals has naturally brought in its train many problems. In the design of many highly-rated machines, engineers are calling for the welding of materials which a few years ago were regarded as unweldable, and as a result of our increased knowledge of the welding process and of the materials themselves the call is often not in vain. Some of the problems being investigated by the British Welding Research Association are outlined in this review of the year's work.

A SURVEY of the work of the B.W.R.A., under the title of "Planned Research in the Welding Industry," appeared in this journal a year ago and briefly sketched the origins and organisation of the Association, and in more detail dealt with the work in progress and the research contemplated.

The twelve months since this last survey has seen good progress in the development of the Association. More equipment has been installed at the metallurgical laboratories at Park Crescent, and at Abington Hall the engineering laboratories and workshops have now been equipped to permit of more extensive work in many aspects of welding. The co-operative work with member firms, with Universities and with other Research Associations amplifies the work at the B.W.R.A. laboratories and helps towards the solution of the many problems that arise from the increasing use of welding in peace-time industry.

Broadly, the work of the Association may be divided into those researches involving the welding of ferrous metals, and those on the welding of non-ferrous metals, with the former naturally predominating, but the theoretical and the practical side of welding and consideration of the various forms of welding subdivides these two branches into many lines of investigation. At present, there are about thirty working committees each guiding different lines of welding research, or concerned with the preparation of memoranda on good welding practices.

In this article progress made during the past year will be summarised; it will be assumed that the previous survey is already familiar, and the broad outlines given there will not be repeated.

The Constitution of Weld Metal

A platinum wound furnace for making tensile tests under vacuum conditions at temperatures up to 1,450° C. has recently been constructed at the B.W.R.A. metallurgical laboratories, and investigation of the hot strength of weld deposits made by two different electrodes with rutile base coatings has been carried out. Certain interesting anomalies have been indicated, and these are being followed up in order to attempt to relate them to those hot cracking tendencies experienced in practice.

Other work on hot cracking tendencies is also being carried out, using as a criterion the well-known T. test.

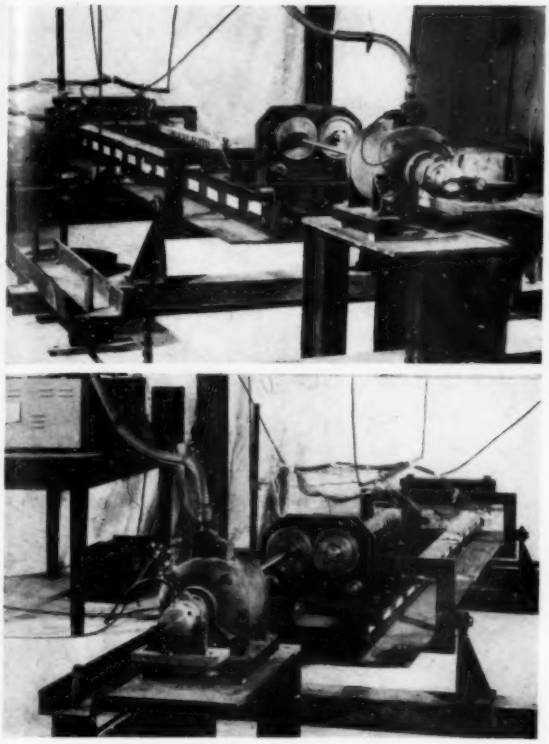
Co-operative research has furthered the investigation on the formation of haloes ("fish eyes") in weld metal and their relation to hydrogen content. One line of investigation has been to make tests at sub-normal temperatures in order to observe the effects on the type of fracture obtained of conditions under which hydrogen diffusion is much reduced. A marked effect on halo formation was noted, thus again linking the phenomenon with hydrogen in the steel.

Weldability of Higher Strength Structural Steels

Work is continuing at the Association's metallurgical laboratories on the weldability of about thirty representative higher strength structural steels and many weldability tests using the Reeve method of test have been completed and the welds are now being comprehensively examined.

Where cracking has occurred the relationship between crack length, fillet size and type of electrode has been investigated, and it has been found that greater consistency is observed if energy input into the weld is used as a basis of comparison instead of the more obvious one of fillet size.

The investigation on metallurgical factors involved in the welding of alloy steels at Birmingham University has continued, with particular attention being paid to the influence of quenching after heating to abnormally



Two views of the general arrangement of a fatigue test set-up for stiffened panels of ships' plating. (Exciter unit in the foreground).

high temperatures. As many factors of fundamental importance in ferrous metallurgy were becoming involved in this work, it was agreed with all concerned that it would be appropriate if the main financial responsibility were taken over by B.I.S.R.A. The B.W.R.A. nevertheless continues to take a strong interest in the work.

Metallurgy of Welding Non-ferrous Metals

The progress made in recent years in the metallurgy of the welding of non-ferrous and light metals is in response to their increasing development in engineering uses. The researches of the Association are being carried out mainly on the practical aspects of the fusion welding of aluminium alloys (including the binary aluminium-magnesium and magnesium-silicide types) and magnesium-base alloys, of the resistance welding of light alloys, and of spot welded structures in light alloys. A basis has also been prepared for the standardisation of tests of welds in light alloys, whereby existing knowledge has been summarised in order to provide a background for future work, and possibly for the preparation of a British Standard.

In an investigation on the arc welding of aluminium alloys, the initial work was the examination in the Association's metallurgical laboratories of welds in thick aluminium-magnesium alloy plate made by manufacturers and users of arc welding electrodes.

The work done has been fairly extensive, but is still of a preliminary nature and amongst the indications so far obtained it appears that low weld strengths are associated with low rates of cooling and with high filler-metal superheating temperatures. As the greater concentration of heat in arc welding has been found to reduce the tendency to blister in the parent metal, it may be inferred that loss of mechanical properties in heat treated alloys would be expected to be considerably more localised with arc welding than with gas welding A long-range programme of research is following these preliminary investigations.

In the fusion welding of magnesium rich alloys, a simple weldability test which is economical in material has been evolved with the co-operation of the N.P.L. who have kindly supplied sheets in various experimental alloys. Tests on gas welds have been made at the B.W.R.A. metallurgical laboratories, and are being compared with tests using argon-arc welding, interest centring on the hot-cracking tendencies of the different alloys welded by different processes.

A full programme of tests on spot welded and riveted light alloy box section members, representative of aircraft construction practice, has completed a preliminary stage. Comparative data on the behaviour under shearing forces combined with normal tensile forces set up by skin buckling on light alloy shear panel specimens are being provided by the tests, which also included fatigue conditions.

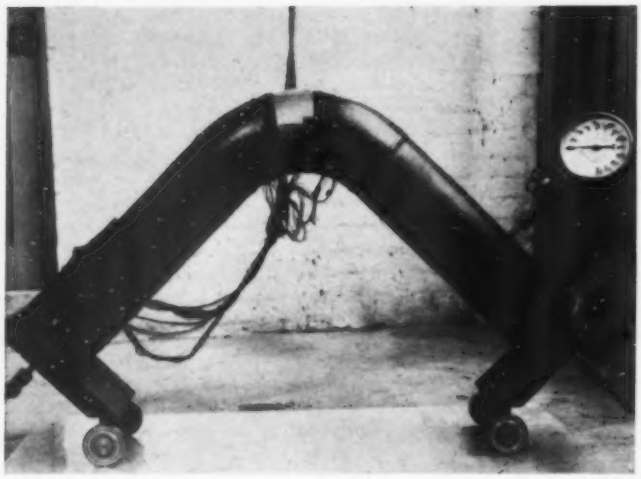
THE APPLICATION OF WELDING

Engineering Researches

Extensive work on the investigation of the behaviour of welded rigid frame structures, which takes into account stress redistribution effects caused by temporary overloading and deformation of part of the structure, is continuing at the B.W.R.A. Abington Research Station, and at the University Engineering Laboratory, Cambridge. For over ten years, Professor J. F. Baker, whose collaboration is invaluable to the Association, and his colleagues have been developing a theory of plastic design with particular reference to rigidly connected frames. To obtain the full advantage from the use of welding, account must be taken of the plastic range in defining the working conditions for a rigid frame structure; unlike the pin-jointed frame, these structures do not necessarily become unserviceable at the first signs of yielding, but may go on to carry considerably more load before collapse.

Tests on the load carrying capacity of small-scale frames and on miniature portal frames which have for the most part been made in the University Engineering Laboratory at Cambridge, are of almost universal technical interest. These have provided information for planning full-scale tests, and the construction of a structure and loading gear for the full-scale tests has now been completed in the grounds of the Abington Research Station. This rig is specially arranged to load a pair of welded portal frames having a span of about 16 feet and a height of about 8 feet. The load is applied by adding weighed sections of tractor track, which can be used for about 75% of the load. The remaining 25% can be added by running water into tanks, each holding 2½ tons of water, which are suspended from the frames. By means of pulley arrangements, a side load is applied to simulate wind pressure on a building.

Parallel investigations are also in progress to provide data from which it should be possible to suggest suitable safety factors for use in designs based on the simple theory of plasticity. As a first approach a statistical examination of the intensity and duration of gusts in a high wind has been made from data published by the



Pipe bend set-up for internal pressure test with strain gauges attached.

Meteorological office and a method is being investigated of stating the probability of failure of a welded structure building when acted upon by a wind of given mean and of given extreme velocity. Very appreciable savings in weight which vary from 15 to 27% may be achieved by the new method as compared with the old conventional designs.

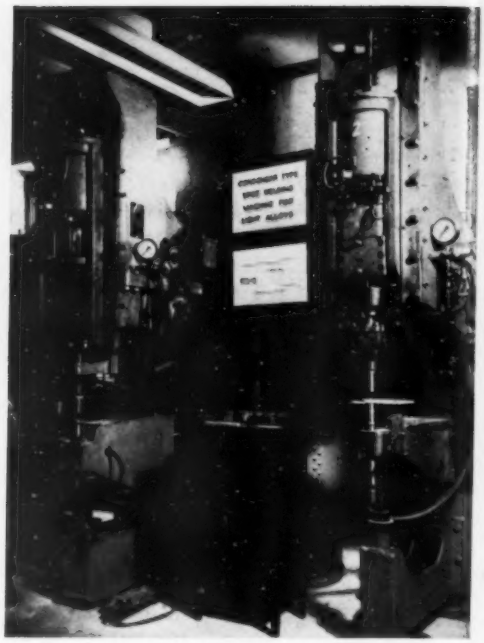
Dynamic Loading Tests

The installation of testing equipment for the investigation of the behaviour of welded structures under dynamic loading has been completed at the Abington Research Station, and tests began early in the year. Fatigue tests are carried out by the resonance vibration method which enables comparatively high stresses to be induced in large specimens by use of low powers. At present two lines of research are being followed—one on the determination of the best method of making welded joints in angle stiffeners of ships' plating, and the other on the influence of internal stresses on fatigue strength. A new inductance strain gauge capable of measuring residual stresses over very small gauge lengths has been developed for use in this investigation. By supporting the test piece at the nodal positions and applying out-of-balance weights driven by a small electric motor, it is possible to obtain stresses in large pieces of over 14 tons per sq. in. during continuous running over long periods.

Consideration is also being given to a number of problems arising from the repeated loading of welded constructions, and a separate investigation, at Manchester College of Technology but in close co-operation with the Association, is being made to determine the effect of flame cutting on the fatigue endurance of mild steel specimens subjected to tensile and bending loading.

Pressure Vessels

Investigations into the stresses in welded pressure vessels, and stress analysis experiments to provide a comparison between welded and seamless pipe bends subjected to internal pressure and to such external forces as would be produced by changes in temperature, are also being made by brittle lacquer and strain gauge



Light alloy spot-welding machines installed at Abington.

techniques at the laboratories at Abington. Much fundamental work has been done, and further investigations are to be made into the stress conditions in and around typical welded branch connections in pressure vessels. A full-scale vessel, 10 ft. long by 3 ft. 6 in. diameter, is being installed so that the various methods of reinforcing openings can be tested. This work will be greatly helped by the loan of a high pressure 10,000 lb. Fielding and Platt pump, driven through a Heenan and Froude electric slip coupling, which has recently been installed. Besides static pressure tests, it is hoped later to carry out further tests under fluctuating pressures.

Amongst other work of the Association concerned with the engineering side of welding are the formulation of recommendations for the design, fabrication and erection of metal arc welded mild steel building structures, for the heat treatment of welded structures, for the specification of electrodes for the arc welding of mild steel, on faults in arc welds, and on non-destructive methods for the examination of welds.

Resistance Welding

A rapid and efficient mass production process for the fabrication of light engineering components in mild steel is by projection welding. Investigations are being made in order to attempt to relate settings of the weld variables with the strength and quality of the welds produced. The main variables involved are the effects of short circuit secondary current, the duration of current, and the applied pressure.

The preliminary investigations were made with single projection welds, and a high degree of consistency was obtained, provided that certain optimum settings of the welding variables were used. Work is being extended to a wider range of sheet thicknesses, and to the welding of studs and bosses to sheet, and on the data obtained

investigations will be made on the formation of multiple projection welded joints.

Much work has been done in investigations into suitable equipment for the measuring of main variables in resistance welding machines. Although these variables are capable of accurate measurement in the laboratory, instruments suitable for use in workshops needed to be devised. A new two-stage current transformer intended for operation in conjunction with the impulse ammeter for the measurement of secondary current has been designed and made, and a design has been prepared for recording dynamic electrode pressure during welding.

Research into the resistance welding of light alloys is being carried out at the B.W.R.A. Research Station at Abington. Installation of two light alloy spot welding machines lent by the Ministry of Supply (one of them the largest in the country) is now complete and a research contract has been obtained from the same Ministry: the work, which is on the strength and consistency of spot welds in the strong alloys of aluminium, is just getting under way.

Investigation into the flash welding of steel, which has recently been in abeyance, will be continued shortly, and further work is to be done on the preparation of a code of practice for spot welding mild steel.

Publications

The main medium for the open publication of reports which have already been in the hands of members for some time, is *Welding Research*, which also appears as a supplement to the *Transactions of the Institute of Welding*. A note of the papers appearing in this place, and of other B.W.R.A. sponsored publications, which have appeared during the past year, is given.

Reports Published in "Welding Research"

Research Supplement to the *Transactions of the Institute of Welding*.

Vol. 1. No. 3. August, 1947.
"A Moment Distribution Method for Rigid Frame Steel Structures Loaded Beyond the Yield Point." "Recommendations for the Standardisation of the Radiographic Examination of Welded Joints in Mild Steel Pressure Vessels." "Arc Welded Structural Steelwork—Built-up Girders and Compression Members. Recommendations for the Design and Fabrication of Welded Members."

Vol. 1. No. 4. October, 1947.
"Photographic Aspects of the Radiography of Welded High Pressure Vessels," by L. Mullins. "Recommendations for the Design, Fabrication and Erection of Metal Arc Welded Mild Steel Building Structures."

Vol. 1. No. 5. December, 1947.
"The Behaviour of the Webs of Plate Girders," by S. R. Sparkes. "Instruments for the Measurement of the Main Variables in Resistance Welding Machines," Interim Progress Report of FR.5 Committee.

Vol. 2. No. 1. February, 1948.
"The Behaviour of Stanchions Bent in Double Curvature," by J. F. Baker and J. W. Roderick.

Vol. 2. No. 2. April, 1948.
"The Measurement of Secondary Current, Voltage and Electrode Load Cycles for Spot Welding Machines," by G. E. Bennett and H. E. Dixon.

Vol. 2. No. 3. June, 1948.
"A Mains Operated Valve Voltmeter for the Measurement of Secondary Current in Resistance Welding Machines," by A. J. Hipperson. "Recommendations for the Design of Arc Welded Mild Steel Machinery Constructions." "The Testing of Light Alloy Fusion Welds."

Vol. 2. No. 4. August, 1948.
"Approximate Methods of Calculating Collapse Loads of Stanchions Bent in Double Curvature," by J. W. Roderick and J. Heyman. "Mechanical Properties and Welding Characteristics of Single Projections in Low Carbon Mild Steel Sheet with Particular Reference to the 14 S.W.G. Thickness," by A. J. Hipperson.

Miscellaneous Reports

"Symposium on the Metallurgy of Steel Welding."
"The Breadths of X-Ray Diffraction Lines from Martensite," by J. A. Wheeler and M. A. Jaswon. (Reprints from *Journal of Iron and Steel Institute*.)
"The Stress System Causing Hard Zone Cracking in Welded Alloy Steels," by J. A. Wheeler. (Reprints from *Institute of Metals Symposium on Internal Stresses*.)
"Residual Stresses due to Welding," by R. Weck. (Reprints from *Institute of Metals Symposium on Internal Stresses*.)
"Recent Progress in the Metallurgy of the Welding of Non-Ferrous Metals," by J. G. Ball. (Reprinted from *Metal Industry*.)
"The Metallurgical Laboratories of the British Welding Research Association," by J. G. Ball. (Reprinted from *Welding*, March, 1948.)
"British Welding Research Association. Research Station, Abington Hall." (Reprinted from *The Engineer*, June 18th, 1948.)
"Research at Abington. B.W.R.A. Engineering Laboratories." (Reprinted from *Welding*, July, 1948, p. 309.)

Production Engineering Research Association

By Dr. D. F. Galloway, Wh.Sc., M.I.Mech.E., M.I.P.E., A.M.I.E.E., B.Sc.Hons., M.Inst.Pet.

Director of the Production Engineering Research Association of Great Britain.

The importance of the work of the Production Engineering Research Association to the economic life of this country needs no emphasis. Whilst the immediate concern of the Association must be with such directly practical problems as machinability and formability, it is hoped that in due course it will be able to co-operate with other laboratories in establishing the fundamental physical behaviour of materials during machining and forming, thereby facilitating the solution of day-to-day problems in industry.

ALTHOUGH for many years facilities have existed in industrial, government, and university laboratories for research into the properties and behaviour of engineering materials and manufactured products, very little research capacity has been available for investigations to improve the efficiency of the operations whereby those engineering materials are converted into manufactured products.

The processes of manufacture commonly used throughout the engineering industry have been developed mainly by trial and error in the factories. In this way immense progress has been made with commercial gain as the great driving force, but it is now apparent that consideration of immediate commercial gain not only stimulated research and development, but also seriously limited its scope in each individual firm. As a result, there have arisen many problems of vital importance to the manufacturing industries which can be solved most efficiently by communal research. PERA has been formed by British industry to meet this need so far as engineering is concerned.

PERA is the Production Engineering Research Association of Great Britain, an Association of engineering firms formed for the purpose of assisting member-firms to improve production efficiency, and receiving considerable government support in recognition of the Association's contribution to improving the efficiency of British industry as a whole. The researches carried out will cover the whole range of production engineering activities, and so lead to improvements in the design and quality of production equipment, and also to the provision of technical data essential for the most

Fig. 1.—External view of first laboratory formed by conversion of existing buildings at Staveley Lodge.

efficient use of this equipment. Already PERA is extending its services to, and receiving the close co-operation of many manufacturers distributed throughout the whole engineering industry of the country, including makers of all types of industrial plant, automobiles, aircraft, industrial and domestic electrical appliances, rolling stock, agricultural machinery, housing and household requirements, etc.

PERA was incorporated in June, 1946, and acquired an eight-acre site at Melton Mowbray in November of that year. Since then, existing buildings have been converted to form about 15,000 sq. ft. of laboratories and workshops in addition to library, lecture room, administrative offices, etc. The gradually increasing staff now numbers about 70, most of whom are in the two main service departments, the Research Department and the Information Department.

The early activities of the Research Department were restricted by difficulties in acquiring machines, equipment and materials, but these are being rapidly overcome and the first general research programme, including machinability, formability, machine tools, cutting oils, etc., is now progressing. As PERA is the first and only production engineering research organisation of its kind in Britain, it is naturally confronted by a huge deficit of production engineering problems, the solutions of which are anxiously awaited by industry. Determining the relative priority of these problems has been difficult, but the main Technical Committee, and its specialist Sub-Committees being comprised mainly of representatives of member-firms ensure that the most urgent needs of production practice are satisfied.

Almost all engineering firms are concerned with some aspect of the problems of machinability and formability as they carry out common operations such as drilling, turning, milling, grinding, blanking, piercing, pressing and deep drawing, or in the application of newer techniques in operations such as impact extrusion, die hobbing, etc. A realisation of the urgent need for precise data regarding the equipment and conditions required for maximum efficiency in metal machining and forming has given rise to an extensive study of machinability and formability. Some indication of the importance of this industrial activity in Britain was given by the Institution of Mechanical Engineers in

Fig. 2.—Drilling research in progress.

1946 when a conference on machinability was organised, including 14 papers covering the physical basis of machinability, the methods of testing machinability, and the effects of cutting conditions and machinability in relation to economy of production.

Although for some time PERA must be concerned with the directly practical problems of machinability and formability, it is hoped that in due course it will be able to draw from other laboratories in universities and government research stations a background of the fundamental physical behaviour of materials undergoing machining and forming operations, thereby greatly facilitating the solution of day to day problems in industry. Links have already been established with these laboratories where long-term generic research is to be undertaken.

The use of cutting fluids, and fluids required in forming operations is so extensive in the engineering industry that any really practical research into production engineering methods and equipment must inevitably involve research into the appropriate fluids. Despite the important part which pressing lubricants, cutting fluids, etc., have played for many years in metal machining and forming operations, their performance has remained remarkably free from reliable quantitative assessment, and the relative effects which different fluids have on the efficiency of the various production operations have remained largely the subject of personal opinions. Fortunately, the progress made in metal cutting research in the last six years has made possible not only the true assessment of the relative merits of the various cutting fluids now available, but has also provided manufacturers with a much surer guide to the development of new cutting fluids. The suitability of

cutting fluids for use in particular machining operations does not depend entirely on factors such as their effects on tool life or permissible cutting speed, but also on factors such as corrosion effects, fuming, physiological effects, etc., and PERA is taking these factors into account in its present investigations.

Research on machine tools must obviously have high priority in the PERA programme, for machine tools are necessary in varying degrees for the production of almost all consumer goods, and also for the maintenance of important industries such as transport and distribution, mechanised agriculture, etc. In view of this important part which machine tools play in sustaining modern life, it is surprising that no country has given adequate attention to the systematic development of machine tools by organised research on a really comprehensive scale. It is a most encouraging portent for the future that PERA is already serving and receiving the whole-hearted co-operation of practically the whole of the British Machine Tool Industry.

With the aid of new equipment specially developed for machine tool testing, a full range of investigations has commenced, including efficiency tests, alignment tests, tests of the deflections of principal machine tool elements, vibration tests, rough and finish machining tests, spindle bearing tests, etc.

The scope of investigations carried out by PERA depends directly on the requirements of member-firms. Experience so far, has been mainly concerned with the cutting and forming of materials, but already consideration is being given to problems connected with methods of assembly, heat treatment, measurement, inspection, etc. The priority given to researches in these and other production engineering activities will be in accordance with the interests of member-firms.

Although most of the researches carried out in PERA workshops are of interest to member-firms as a whole, arrangements have been made whereby special investigations of a confidential nature are carried out for individual firms. These facilities are already widely used, for it is inevitable that manufacturers should have problems not of general interest, but concerning their particular products and manufacturing methods. Such investigations are carried out for both makers and users of production machines, equipment, and materials. In order to speed up the application of tests PERA has developed designs of dynamometers, etc., which have been made available to member-firms to enable them to carry out in their own Research Departments the tests for which the equipment has been developed.

At the root of many production engineering problems is the urgent need for a "yardstick," a properly established measure whereby important factors such as machinability, formability, etc., can be accurately compared. It is not difficult to imagine how chaotic life would be if we had no mile to measure our roads, no hour to measure our days, and no pint for our fluids. That is exactly the position with the many factors vitally affecting production. There is also a complete absence of simple accepted units for the measurement of machinability or formability, or the performance of various tools and machine tools, or the performance of cutting fluids, etc., and until such units and standards are developed on a sound basis, production engineers will have to continue to rely on the personal opinions of machine operators and foremen, or on the persuasion of salesmen.

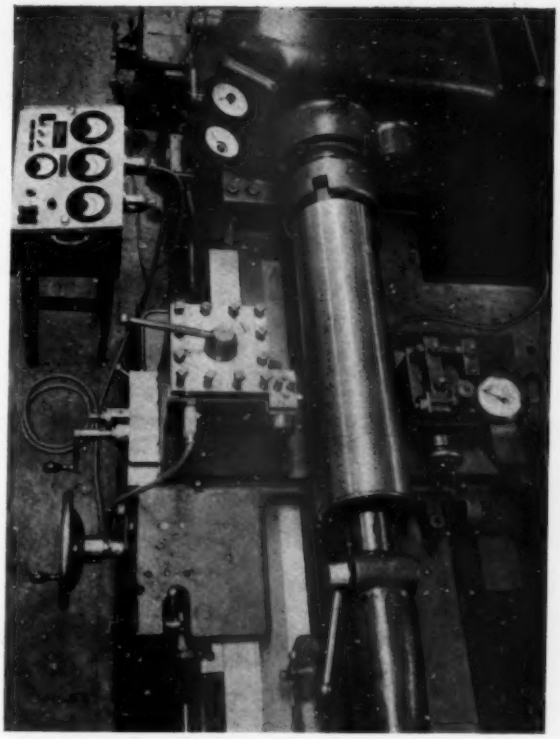


Fig. 3.—Set-up for rough turning tests showing triple element tool dynamometer in front tool post, and special Brinell tester in rear tool post to facilitate frequent checking of machined material. The 30-in. swing lathe, with a 60-h.p. drive and infinitely variable speed was specially designed for turning and lathe tool investigations.

One of the objectives of PERA is to develop simple tests and standards so that these elements of production which have so long eluded control and which constitute some of the chief sources of inefficiency, can be removed from the realm of personal opinion and conjecture to that of clear discrimination made possible by precise measurement. The small team of research workers which ultimately formed the nucleus of PERA staff was engaged on production engineering research for about six years prior to the formation of PERA. Most of the sixty investigations carried out during that period involved the solution of special war-time problems, and the results have not been published. Reports on the more general investigations have been prepared, a particular example being the book "Practical Drilling Tests" which shows how the overall economic efficiency of the common operation of drilling can be greatly increased by applying the results of these investigations to the selection of drilling conditions, the grinding and inspection of drills, the selection and application of suitable cutting fluids, and the selection and efficient use of drilling machines, drill-holding devices, etc. The potentialities of such research results can be estimated from the fact that Britain's consumption of drills before the outbreak of war was approximately 40,000,000 per annum, that thousands of drilling machines are continuously engaged on drilling operations, and that many more thousands of lathes, capstans, and automatic

machines are frequently used for drilling. The investigations carried out by this small team during the war showed conclusively that a few hundred pounds spent on this type of production engineering research can save or yield as many thousands of pounds per annum in a single factory if properly applied.

Practical investigations into the techniques of production processes inevitably form a large part of the activities of PERA, but in addition to research, various auxiliary services of considerable value to member-firms have already been developed. Most of these services are dealt with by the Information Department. A monthly PERA Bulletin is issued containing production engineering abstracts effectively classified so that new information relating to particular aspects of production engineering can be found with the minimum loss of time. The abstracts cover a wide range of British and foreign technical periodicals and other reports acquired by the Association. Complete copies of articles and reports abstracted in the Bulletin are supplied on request. The circulation of PERA Bulletins is not restricted to the offices of member-firms, but in most cases extends throughout the works, including all foremen. Sufficient copies of the Bulletin are sent to each member-firm to ensure that the Bulletin and the services which are given with it are made available throughout the factory within a few days of publication. PERA information service includes the answering of technical queries. This service has been extensively used during the past year, and the queries have covered a very wide range of production engineering problems. Special efforts are made to ensure that this is a really practical service, and the PERA engineers dealing with these problems take into account any peculiar conditions relevant to each problem, e.g., shortage of standard materials, protracted deliveries of materials or equipment, shortage of suitable labour, increased costs of materials, etc., appertaining at that time in the particular branch of industry concerned.

The aim of PERA is not merely to produce research results, but also to ensure prompt and effective application of these results. It is upon this policy that the success of production engineering research depends, and it is a policy which is vigorously pursued. One of the most effective means of ensuring prompt application of results is the member-liaison service which includes frequent visits to all member-firms by PERA research engineers, thus ensuring the closest collaboration between PERA and the production personnel in member-firms. This form of personal contact has already proved of great value to member-firms, and in future, PERA research engineers will visit all member-firms at least three times each year.

Further developments designed to assist the application of research results are in the form of educational activities, the first of which have recently been arranged. Although the results of practical investigations are to be concisely presented in the form of reports, booklets and instructional manuals for use in the workshop, this information is often much more effectively applied as a result of demonstrations, lectures, conferences, and other meetings which are being organised at Staveley Lodge for the benefit of the personnel from member-firms. Arrangements are also being made for a limited number of particularly good apprentices and key production personnel to spend periods of about six months in PERA workshops and laboratories in order to absorb information on production research techniques and to acquire the research outlook on production problems.

The increasing tempo of everyday life is reflected in increased rates of industrial development which in turn give a sense of great urgency to those research projects ultimately associated with workshop equipment and methods. This urgency is not related merely to the identification of research problems and the discovery of their solutions, but extends to the application of results. Only prompt application of the results of individual investigations will bring to fruition this practical research which has such immense potentialities. The two tasks are research and education, and in undertaking these tasks it is important to realise that production engineers constitute an intensely practical section of industry, and research workers in this field know from experience that it is not easy to persuade foremen, superintendents, and key workers to put their professional pride in their pockets and drop their old prejudices in favour of new techniques. Nevertheless, this is a task that must ultimately be accomplished. Any attempt at enlightenment must eventually penetrate to the man who is actually doing the job, for only then will industry and the nation derive maximum benefits from these efforts.

Corrosion of Metals Research

Progress Report of the Chemical Research Laboratory

In the recently published Report of the Director of the Chemical Research Laboratory, many aspects of the Laboratory's work on the corrosion of metals are discussed. The extracts presented here record the progress made in the fields of organic inhibitors and microbiological corrosion.

MUCH of the work carried out in the Corrosion Section of the Chemical Research Laboratory reviewed in this Report, continues or amplifies work initiated during the war years for Service and other Departments. An outstanding exception is microbiological corrosion, for which an entirely new and comprehensive programme has been planned. Other exceptions are corrosion-testing technique and the study of surface films, both of which formed part of the pre-war programme. Of the many branches of corrosion research work carried out and referred to in the report, those dealing with organic corrosion inhibitors and microbiological corrosion have been selected for presentation in these columns.

ORGANIC CORROSION INHIBITORS

Immersed Conditions

The value of sodium benzoate both as a freezing-point depressant and as an inhibitor of corrosion in natural waters and neutral solutions was demonstrated

in the course of work on anti-freeze materials.* An extensive search is now being made for organic corrosion inhibitors more efficient than sodium benzoate (i.e., completely protective at lower concentrations). These experiments use mild steel specimens immersed in open vessels in distilled water of ordinary laboratory purity; the work will later be extended to typical supply waters.

A series of pure sodium salts of various organic acids has been prepared by neutralising the acid with sodium hydroxide. In the earlier work 1% of the sodium salt was used as the inhibitor in mains water, and this served to select the most promising of many acids investigated. Subsequently, concentrations of 0·01, 0·025, 0·05, 0·075 and 0·1% in distilled water have been employed, these serving to indicate the region of the critical concentration.

Besides these exploratory tests, more critical experiments are being carried out to compare the inhibitive effects produced by the newer organic reagents (e.g., sodium benzoate and sodium cinnamate) and the more conventional inorganic inhibitors such as sodium chromate and sodium nitrite. For these experiments, turned mild steel discs are totally immersed in special vessels inside a cupboard at reasonably equable temperature; concentrations over the range 0·001 to 1·5% in distilled water are being studied.

Specimens showing appreciable corrosion after 28 days are removed, derusted and re-weighed. It has been confirmed that corrosion resulting from insufficient inhibitor is general and uniform with the organic inhibitors but localised with sodium chromate. The total loss of metal is sometimes increased up to 30% (as compared with the loss in distilled water) by addition of too little organic inhibitor, whereas the loss with insufficient chromate is less than with the "control."

Electrode potential measurements indicate that sodium benzoate functions as an anodic inhibitor, but further work is necessary to decide the precise mechanism e.g., whether the benzoate is preferentially absorbed at anodic areas.

Atmospheric Conditions

The work on inhibitors under atmospheric conditions has concerned the protection of metal articles by introducing the corrosion inhibitor into the wrapping material and the prevention of corrosion in confined air spaces by the use of volatile ("vapour phase") inhibitors.

Wrapping Materials.—The protection afforded to iron and steel surfaces when wrapped in paper or cellulosic films impregnated with sodium benzoate† has been amply confirmed; complete absence of rusting has been found after prolonged exposure in a warm humid atmosphere (intermittently precipitating moisture) in which specimens wrapped in untreated paper have rusted severely.

The use of temporary protective greases for steel has been investigated in conjunction with benzoate-treated wraps. Five such greases were tested in conjunction with a standard oil paper and with cellophanes impregnated with various amounts of sodium benzoate. Results showed that "benzoated" cellophanes are the most satisfactory.

Exposure tests under Ministry of Supply auspices at Lagos, Nigeria, employed steel gudgeon pins with brass ends as specimens. Wrapped in untreated cellophane these were heavily rusted in 11 weeks; in benzoate-treated cellophanes (2, 4 and 6% sodium benzoate) they were completely protected.

"Vapour Phase" Inhibitors.—Besides alkyl benzoates‡ the effects of various cinnamates in the vapour phase have been examined; of these, amyl and methyl cinnamate have shown the most promise. The method of examination consists in the very slow aspiration of air, saturated with water vapour at 35°, through vessels containing the reagent, above which the metal specimens are suspended. The specimens are loosely wrapped in filter paper in order to increase the rate of attack on control specimens; in the absence of such contact corrosion proceeds unduly slowly.

Some further compounds have now been prepared from organic bases; preliminary trials have yielded very encouraging results.

MICROBIOLOGICAL CORROSION
(Especially of Buried Metals)

Sulphate-reducing bacteria are now generally recognised as essential agents in the anaerobic corrosion of iron and steel, and perhaps of other metals, buried in soil. Their function, not yet decisively proved, is believed to be that of rendering the oxygen of sulphates present in soil available for depolarising the cathodic metallic areas in the electro-chemical corrosion process. It would seem possible for other soil micro-organisms to perform an analogous function. For example, nitrate-reducers in the presence of nitrates should theoretically be able to act in a similar manner and likewise any organism able directly to oxidise hydrogen. The work now described concerns only sulphate-reducers but the part played by other bacteria has been kept in view for future investigation.

Stock Cultures.—Hitherto, pure strains of sulphate-reducing bacteria have been kept on artificial media and there is reason to believe this procedure has some influence on their properties. For the study of nutritional requirements and biochemical properties it is desirable to lay down a "cellar" of any organism to be investigated in a form in which the organism is likely to remain stable and normal. Trials were therefore made with sterile clay and sterile sand as stock culture media, clay and sand being natural habitats for sulphate-reducing bacteria. Three drops of actively growing cultures of three different strains were incorporated in about 5 grams of moist sterile medium contained in test tubes which were then plugged with cotton wool saturated with alkaline pyrogallol and finally sealed. After four and again after seven months, all three strains on clay developed vigorously when transferred to ordinary laboratory media; no growth was obtained from those on sand. Similar clay cultures will be tested for viability periodically. All newly isolated strains are now put on to this clay medium.

Culture of Sulphate Reducing Bacteria.—It was early apparent that the techniques available for the culture of sulphate-reducing bacteria would be inadequate for future requirements. Large quantities of uncontaminated cells would be needed for mass inoculants in accelerated tests, for the study of the respirations of cell suspensions by manometric and other methods, and for the examination of the mechanism of the corrosion process. The methods of anaerobiosis used for their cultivation were found to be unsuitable for extensive laboratory manipulations. Considerable attention has

* Brit. Pat. 569,364/45.
† Brit. Pat. Applic. 13,320/45.
‡ Brit. Pat. Applic. 18,824/45.

therefore been given to the development of improved methods of culture.

Fresh media have been devised which give rapid and prolific growth without the formation of ferrous sulphide, thus permitting the harvesting of considerable quantities of uncontaminated cells for biochemical examination; the measurement of growth by increasing turbidity of the medium has also been made possible. The main factor causing increased growth has been the addition of 0·05% Difco yeast extract to the sulphate-lactate medium of earlier workers. Freedom from ferrous sulphide is obtained by adding to the medium not more than 2 mg. Fe^{++} per litre, which is sufficient for the essential iron requirements of the organism but is below the saturation concentration of the sulphide. Of the anaerobic techniques investigated, the use of the McIntosh and Fildes anaerobic jar was found to be the most satisfactory for general use, though for some special purposes it is better to use sealed stoppered bottles completely filled with medium. The employment of culture tubes, plugged with cotton wool soaked in alkaline pyrogallol and sealed with paraffin wax, though inconvenient for general manipulation, is useful when no anaerobic jars are available.

Some difficulties were experienced initially in growing sulphate-reducing bacteria on solid media, but these have largely been overcome by the introduction of new media and it is now possible to obtain good growth on slopes and to "plate-out" a culture on petri-dishes in an anaerobic jar. This has greatly eased the isolation and purification of new strains from natural sources such as soil and river mud, hitherto a tedious and uncertain procedure. Partial preliminary purification can be obtained by incubating the soil or mud in a simple lactate-sulphate medium to which 5% sodium sulphite ($Na_2SO_3.7H_2O$) has been added.

Effect of Sulphite on Morphology of Cell.—The investigation of the purifying effect of sodium sulphite on the complex soil microflora during isolation of pure cultures led to the observation that sulphite exerts a remarkable influence on the morphology of sulphate-reducing bacteria. The short (2-5μ) comma-shaped vibrio form in normal cultures is replaced in cultures containing 5% $Na_2SO_3.7H_2O$ by long spiral cells, in some cases as many as twelve turns being observed in a spiral. All strains so far isolated are susceptible to alteration in form by sulphite, some to a much greater degree than others.

Autotrophic Growth of Sulphate-Reducing Bacteria

Starkey and Wight* reported reduction of sulphate to sulphide by *impure* cultures of sulphate-reducing bacteria growing in a strictly mineral medium containing bicarbonate as sole carbon source, and in the presence of molecular hydrogen. It was not shown conclusively that pure cultures could grow in these autotrophic conditions.

Pure cultures of four strains of *Vibrio desulphuricans* were subcultured into a medium containing sodium bicarbonate as sole carbon source, ammonium chloride as nitrogenous nutrient, dipotassium hydrogen phosphate, calcium sulphate and magnesium sulphate. They were incubated at 30° C. in an anaerobic jar containing an atmosphere of hydrogen with 5% carbon dioxide. At first growth was obtained with one strain only and attempts were made with the other three strains to acclimatise them to growth in media containing gradually decreasing quantities of lactate (the usual carbon source for heterotrophic growth of sulphate-reducers). This procedure has been found to be unnecessary and growth has now been obtained with all four strains by direct inoculation into the mineral medium.

In final and conclusive experiments, stringent precautions were taken to ensure the total absence of organic material. All glassware used in the preparation of media and for culture vessels was washed in chromic acid and finally in conductivity water. The cotton wool plugs normally used in medium flasks and in culture test tubes were replaced by loosely fitting beakers or tubes washed in chromic acid. Pipettes, instead of being wrapped in paper and dry sterilised, were placed inside large glass tubes and autoclaved. The medium was made up with Analar chemicals and conductivity water.

The growth has persisted through many subcultures into the same medium (using similar precautions), thus obviating any "carry-over" effect of organic material from the original inoculant. Numerous platings-out on various media both aerobically and anaerobically have shown the cultures to be quite pure at all stages. It follows that sulphate-reducing bacteria may now be regarded as facultative autotrophs.

All attempts to cultivate the autotrophic strains in the absence of hydrogen have failed and it is presumed that they obtain their energy for growth by the oxidation of hydrogen, in which process sulphate, as the hydrogen acceptor, is reduced to sulphide. When, however, rods of carefully cleaned sterile mild steel are placed in the inoculated mineral medium and incubated at 30° in a closed jar containing alkaline pyrogallol, definite growth occurs with reduction of sulphate to sulphide.

Applied Investigations

Field Experiments at Chigwell, Essex.—Advice has been given to the Metropolitan Water Board on the protection of ten miles of water mains to be laid in clay soil on a new L.C.C. Housing Estate at Chigwell, Essex. Samples of clay taken from various parts of the estate all showed the presence of sulphates and sulphate-reducing bacteria and *p*H values favourable for growth of the bacteria under the anaerobic conditions induced by the clay. It was concluded that the laying of inadequately protected pipes direct into the clay would inevitably lead to severe corrosion of the anaerobic microbiological type. Recommendations have been adopted whereby the pipes are protected externally by a $\frac{3}{8}$-in. bituminous coating, the best procedure in the present state of knowledge.

As a result of the very helpful co-operation of the M.W.B. authorities, experimental stretches of piping of about 50 yards in length, each incorporating one of the following methods of protection, were laid down on the Chigwell Estate. A site was selected in which conditions were roughly comparable for all the experimental lengths.

(*a*) Treatment by simple immersion in molten tar, which may be regarded as virtually unprotected from the point of view of microbiological corrosion.
(*b*) Protection with $\frac{3}{8}$-in. bitumen.
(*c*) Protection with 3-in. Aluminous Cement.
(*d*) Protection with 3-in. Portland Cement.
(*e*) Treatment as in (*a*) with provision of 9-in. gravel

* "Anaerobic Corrosion of Iron in Soil," Final Report of American Gas Association Iron Corrosion Research Fellowship, 1945.

surround—i.e., for preventing anaerobic conditions next to the pipe.

Periodical inspections of the pipes will be made, the first after three years. These experiments are concerned with protective measures which are known to be immediately practicable but on which no comparative experimental data exist. Further experiments on a smaller scale, and involving the use of untried materials such as plastics, are being arranged, in co-operation with Metropolitan Water Board and British Cast Iron Research Association.

Buried Transformer Tanks.—A request was received from the County of London Electric Supply Company for advice on the protection of projected new steel transformer tanks to replace cast-iron tanks now in service. These tanks are buried just below ground level, many in clay and heavy soils. The question arose whether the new tanks, made of steel $\frac{3}{8}$ in. thick, will resist corrosion so well as the present $\frac{3}{4}$ in. thick cast-iron tanks. Doubt existed whether microbiological corrosion does in fact constitute a problem with these tanks, as considerable heat is generated and the outer surfaces of many of the tanks are held at temperatures of 60–80° C. for considerable periods; it was uncertain whether sulphate-reducing bacteria could exercise their presumed corrosion function in these conditions. Inspection of an excavated tank, which had been buried in heavy London clay for over twenty years, made it apparent that microbiological corrosion is able to take place even in these abnormal temperature conditions. Considerable areas of the tank were covered by a black sulphide scale and there was appreciable graphitisation, though not to the extent of danger of perforation. It was evident, however, that the substitution of a thinner steel tank might lead to perforation through anaerobic corrosion. Recommendations for protecting the new tanks have been made. The investigation of this unusual type of corrosion at abnormal temperatures is being continued and arrangements are being made to equip one tank with a device for recording the temperature of its exterior surface.

Marine Corrosion.—Advantage has been taken of the examination of fouling of ships' hulls in dry dock at Liverpool (by a member of the group working on Anti-Fouling Research for the Marine Corrosion Sub-Committee, British Iron and Steel Research Association) to arrange for a search for evidence of anaerobic microbiological corrosion. Samples of black corrosion products taken from underneath large paint blisters on three ships have been examined at C.R.L. All three samples gave copious evolution of hydrogen sulphide on treatment with dilute hydrochloric acid, and sulphate-reducing bacteria were found to be present in considerable numbers. Pitting of the metal under the paint blisters was reported, and it is concluded that this was due at least partly to the activities of the bacteria.

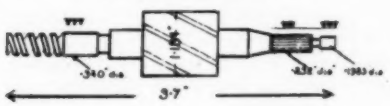
Corrosion of Buried Water Pipe Systems.—Arrangements have been made with the Research Co-ordination Committee of the Institution of Water Engineers for linking up their own programme of research with the work on Soil Corrosion at C.R.L. A detailed questionnaire has been sent by the Institution to certain of their members with a view to obtaining a comprehensive picture of the extent and type of corrosion experienced in a wide variety of soils. It has been agreed that samples of corroded pipes and accompanying soils, together with answers to the questionnaire, shall be sent to C.R.L. for examination.

Centreless Plunge-Grinding

Interesting Developments for Automatic Operation

POST-WAR manufacturing difficulties in regard to labour costs and shortages have greatly stimulated the development of automatic machinery in all fields where its application is possible, and in no industry has this trend been more marked than in connection with centreless grinding, a process which has always been remarkable for its high tempo of production. One of the most interesting of these developments has been the application of automatic operation to the process of plunge-grinding or " in-feed grinding " as it is sometimes termed, which is now rendered possible by the controlled-cycle method of advancing and withdrawing the control wheel head when grinding shouldered, taper, or form work. For this purpose numbers of extremely interesting

Fig. 1.—Small motor shaft assembly ground on three diameters.



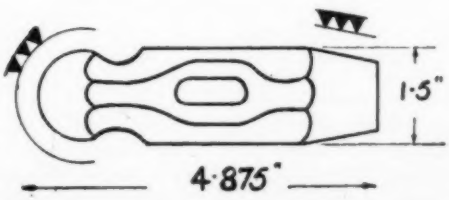


Fig. 2.—Hammer head ground on taper and ball.

Fig.3. **Fig.4.**

Fig. 3.—Vertical-lift magazine, loading position.
Fig. 4.—Vertical-lift magazine, grinding position.

magazines have been evolved which may be classified broadly into eight main types.

For grinding such pieces as the small electric motor shaft assembly (Fig. 1) or the engineer's hammer head (Fig. 2), the type known as the vertical lift magazine is used applied to a Scrivener* controlled-cycle centreless grinder. It will be recognised that either piece would present considerable difficulties in handling if any attempt were to be made to grind it on a normal centreless machine having merely a $\frac{1}{16}$ in. movement to the control head for the purpose of applying the cut and opening the wheels again, owing to the possibility of damage by accidental contact with the grinding wheel when the piece was being placed on or removed from the workplate. This problem is solved by the adoption of the semi-automatic vertical lift magazine applied to a controlled-cycle machine, as shown by the illustrations in Figs. 3 and 4. The working principle of the magazine can be more readily followed by reference to the diagram in Fig. 5, which shows the pivoted carrier arm "A" with a hinged cage "B," which is arranged to rise and fall by the operation of the small hydraulic cylinder "C." Moving between two limiting stops, the piston rod of this cylinder actuates the small lever "D" which is keyed on the same shaft as the carrier arm, and consequently raises or lowers the cage "B." The correct path for the piece to follow in its downward movement to the workplate is determined by the contour of the cam attached to the side of the cage, which makes contact by gravity with the fixed pin "E." The operation of the cylinder actuating the rising-and-falling cage is controlled by solenoid-operated hydraulic valves from the slide of the controlled-cycle unit which alternately advances the wheel to apply the cut and withdraws on completion of the grinding process.

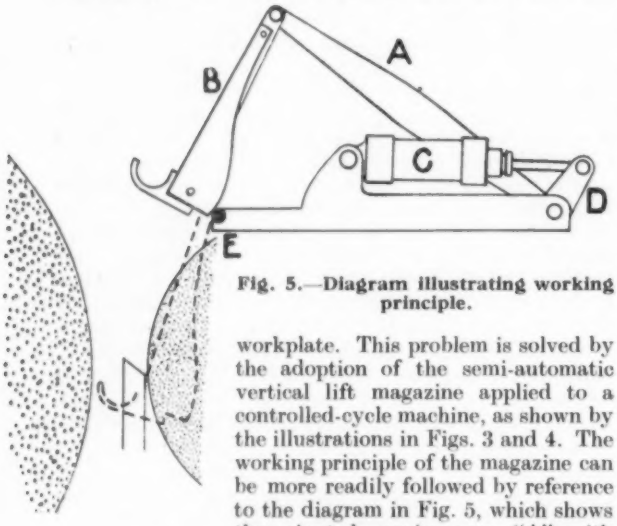


Fig. 5.—Diagram illustrating working principle.

The operator places a piece in the cage when it is in the raised position, and depresses the starting lever on the machine. From this point the operation is automatic; the cage lowers the piece on to the workplate, and when it is in position the controlled cycle of the centreless machine is energised, the wheels advance, and the piece is ground. It is impossible for the controlled cycle slide to come into operation and for the wheels to come together until the piece is correctly in position on the workplate. After grinding, the wheels again open, and when they reach the fully open position, the carrier arm with the finish-ground piece is automatically raised to the "Up" or loading position, and the machine comes to rest for the operator to remove the ground piece and to substitute a fresh one. An automatic safety shutter is provided to prevent any possibility of the operator inadvertently dropping a piece between the wheels.

In the case of the motor shaft assembly, with a stock removal of 0·005 in., this is plunge-ground on three diameters to limits of plus-minus 0·0001 in. at the rate of 300 per hour. The stock removal on hammer heads is much greater, being from 0·020 to 0·050 in., and these can be ground on the taper and ball peine end at the rate of 200 per hour.

* Makers: Arthur Scrivener, Ltd., Tyburn Road, Birmingham.

Hiduminium 51

A NEW alloy has been added to the well-known Hiduminium ranges. It is Hiduminium 51 and has been evolved for sand and gravity die-casting from types used extensively during the war for a wide variety of aircraft components. This alloy is readily available as a competitive-priced alternative to Hiduminium 20, D.T.D. 424; while certain of the mechanical properties have been improved. It has a lower silicon content and is more easily machinable than D.T.D. 424, with an equal—in some cases better—resistance to corrosion. The alloy has good casting characteristics and it lends itself readily to anodic treatment. Data concerning Hiduminium 51 has recently been published, copies of which are available on application to High-Duty Alloys, Ltd., Slough, Bucks.

Nuffield Foundation Research Fellowship in Extraction Metallurgy

THE Nuffield Foundation has provided funds for the establishment of a Research Fellowship in Extraction Metallurgy, which will be awarded in consultation with the Institution of Mining and Metallurgy and the Royal School of Mines, London, and will be tenable at the Royal School of Mines for a period of five years.

Applications, stating the candidate's qualifications and experience and the names of three referees, together with suggestions as to the lines of research it is proposed to follow, should be sent to the Secretary, The Institution of Mining and Metallurgy, Salisbury House, London, E.C. 2, to reach him on or before November 30th, 1948.

Birmingham's Salvage Plans

ONE of the biggest industrial salvage campaigns yet launched in Britain is scheduled for the Birmingham district from September 27th to October 2nd, 1948. Scrap metal of all kinds will be included in the "clean sweep" which industrialists in the district are asked to apply to their plants. The emphasis, however, will be on ferrous scrap and waste paper. In Smethwick's recent campaign, scrap-metal collection is estimated to have risen by 300%. If Birmingham's drive achieves only half this increase it will have produced thousands of tons of valuable metal.

Mr. J. J. Gracie, Chairman of the Midland Industrial Salvage Advisory Council (and General Manager of G.E.C.), is appealing to all works, big and little, to make the campaign an outstanding success, for the need is vital now. All the secretaries of the Birmingham Salvage Groups are co-operating, and the Regional Recovery Office, Board of Trade, C.M.L. Building, Great Charles Street, Birmingham, 3 (Telephone: Birmingham Central 8231—Exts. 180 and 231) is to be the headquarters for the campaign.

Micro- and Macro-Deformations of Metals and Alloys under Longitudinal Impact Loads

By Dr. Georges Welter

(Professor of Applied Mechanics, Ecole Polytechnique, Montreal, Canada.)

The usual testing methods for studying the behaviour of metals are static methods. They give no information of the behaviour of the materials under dynamic loading conditions. Furthermore, the methods using impact loads, as the Charpy or the Izod tests, give no direct information to the designer of machine members who needs data about the elastic limit and the micro-plastic deformation of these materials under dynamic stresses. In order to make some contribution to the problem of the dynamic elastic properties of metals and their micro- and macro-deformations, this investigation was carried out, using gradually increasing longitudinal impact loads. Special shock-proof instruments, permitting measurement of very small permanent deformations in the axis of the specimen, were developed, and three different loading methods described in this article were tried out to find that one giving the most reliable results.

INTRODUCTION

IT is a well-known fact that the investigation of specimens under slowly applied, or static, loading does not tell the complete story about the true characteristics of most materials. Attempts have been made to study the behaviour of materials, working under heavy service conditions, by using dynamic stresses produced under single or multiple impulses. By these methods, however, only the ultimate resistance under dynamic loads may be investigated, this being the objective aimed at by the study of the brittleness and the notch sensitivity of metals and alloys (Izod, Charpy). For the designer, however, who needs information about the elastic limit and the microplastic deformation of dynamically loaded elements, these methods give no satisfactory results. There are only a few metallurgical research institutes in the U.S.A., or Canada, making studies on the behaviour of structural materials under dynamic test conditions. According to the standardised dynamic testing methods of to-day most materials are investigated chiefly with regard to their plastic properties under impact bending or tension loads up to rupture. However, most materials used for mobile structures are serviceable only within the elastic range and all tests on the ultimate breaking load and the total energy absorbed are of no practical use for the design of these structures. No dynamic load should ever stress materials up to or above their elastic limit. Strange to say, there does not exist any precise dynamic testing method by which the designer may acquire the data necessary to predict the behaviour of materials. In fact, the dynamic elastic limit of most structural materials is not at all or not sufficiently investigated.

Besides the two methods, described by the author [1-4], permitting measurement directly on the shock-loaded specimen of its dynamic elastic limit, it seems that no further work has lately been done on this rather important subject. In Table I are shown some results of a few previous investigations of this subject. Other publications related to this problem are given in the attached bibliography.

The present investigation was carried out in order to make some basic contribution to the problem of dynamic elastic and plastic properties of metals and alloys and their micro- and macro-deformations under increasing longitudinal impact loads. Started in 1943,

1. G. Welter. *Zeit. f. Metallkunde*, 1924.
2. G. Welter. *Zeit. f. Metallkunde*, 1925, p. 109.
3. G. Welter. *Zeit. Verein Deut. Ing.*, 1926, pp. 644 and 772.
4. G. Welter. *Zeit. f. Metallkund.*, 1936, p. 257.

TABLE I.—SOME TEST RESULTS OF THE AUTHOR ON THE DYNAMIC ELASTIC LIMIT UNDER TENSION AND BENDING LOADS.

Type of dynamic loading and specimen	Material tested	Dynamic elastic limit Impact loads		Published
		cm. kg./cm.²	Perm. def. at	
TENSION: Specimen 8 mm.⌀ 60 mm. gauge length Pendulum hammer 10 m. Kg.	Brass: ann.	5	0·002% elongation	*Z.f. Metallkunde*, 1925, page 109
	Al: hard	10		
	Steel: mild annealed	90		
BENDING: Specimen rectangular 10×20×120 mm.	Al: ann.	0·5	Angle of 0·5 min.	*Z.f. Metallkunde*, Jan. 1924
	hard ..	1·0		
	Al: alloy 17 ST ..	5		
	Brass: ann.	4		
	hard	18		
	Steel; mild ann. ..	7–8		
	As received	11–12		
BENDING: Cylindrical specimen with notch:— 12·5 mm.⌀ width 4·5 mm. ... radius 2·7 mm.	Al: ann.	0·1	Angle of 0·2 min.	*Z.d. Verein Deutscher Ingenieure*, 1926, No. 20, page 644; No. 23, page 772.
	As received	1·0		
	Al: Alloy I ann. ..	0·5		
	heat treated ..	2·0		
	Al: Alloy II heat treated	3·5		
	Magm.: alloy	1·5		
	Copper: ann.	0·1		
	As received	1·5		
	Brass: ann.	1·5		
	As received	2·5		
	Steel: mild annealed	2·0		
BENDING: High temperature, cylindrical specimen with notch:— 12·5 mm.⌀ width 4·5 mm. radius 2·7 mm.		Temperature 20° C. / 300° C.		
	Al: alloy	1·0 / 0·3	Angle of 1 min.	*Z.f. Metallkunde*, Sept. 1936, page 257
	Steel: mild annealed	2·7 / 0·7		
	Steel: Cr–Ni	8 / 7·6		

The author wishes here to record his thanks to the Council, as well as his appreciation to Mr. A. Olynyk, a student at the Ecole Polytechnique of Montreal, who helped in the preliminary investigation work which he subsequently described in his graduation thesis in May, 1944.

it was made possible through funds from the National Research Council, Ottawa (Committee on Assisted Researches).

The loads were applied to cylindrical specimens of structural materials by gradually increasing the energy ; after each dynamic loading the effect was checked by special shock-proof instruments, permitting the measurement of very small permanent deformations in the longitudinal axis of the specimen. These instruments must be very sensitive in order to indicate extremely small permanent deformations. The impact loads have been produced either by a pendulum hammer, or by a dead weight falling vertically on a transverse beam attached to the specimen, while the elongation of the specimen has been measured after each load by special extensometers.

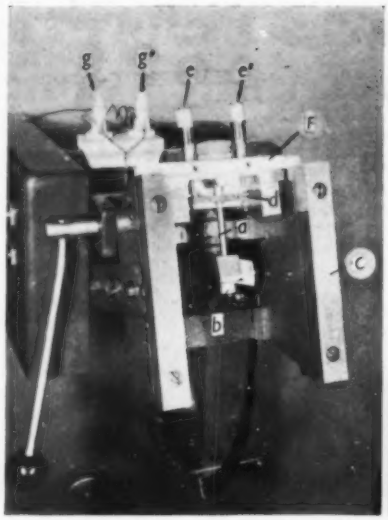


Fig. 2. Special extensometer

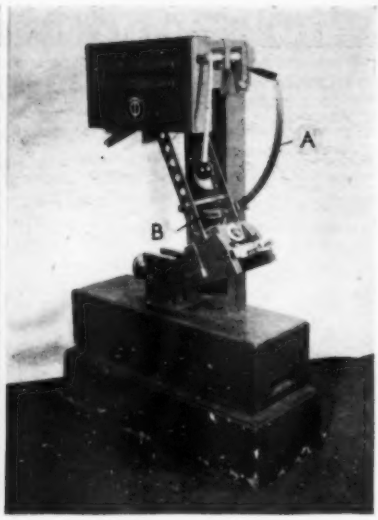


Fig. 3. Olsen impact tester

Theoretical Calculations of Elastic Forces

By assuming that all the energy of the impact, produced by a weight W falling from a height h on a transverse T screwed on the specimen S (Fig. 1), is transmitted to the specimen, an approximate solution of this problem can be found mathematically. It is evident that in order to secure reliable results, the weight of the specimen S with its transverse T must be very small compared to the weight W. The work done by the weight W will be $T = W\ (h + e)$, where e represents the total elongation of the specimen under the impact load. If a static load P is considered as gradually producing the same deformation e, then we will have the equation $W\ (h + e) = \frac{1}{2}\ Pe$. The final formula used for calculating the unit stress (neglecting the small amount of e compared to h) will be :—

$$S = \sqrt{\frac{2E}{al} \times \frac{Wv^2}{2g}} \ *$$

This equation can be used to compare the static loads with the dynamic ones, provided the modulus E is dynamically determined. This has not yet been done ; and assuming the dynamic modulus for these comparative tests to be equal to the static modulus of elasticity, this equation No. 1 may give some possibility of calculating the stresses between the two kinds of loading. However, in order to have more reliable results by which to determine the elastic limit of dynamically loaded specimens, the following experimental investigation has been carried out giving, by direct observation, results which may be compared with those calculated by different methods.

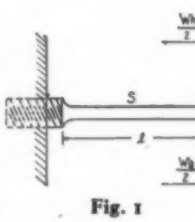


Fig. 1

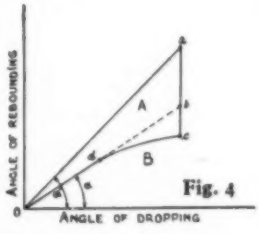


Fig. 4

Preliminary Experimental Tests. Method 1.

First, to get some information about the behaviour of various materials under dynamic impact loads, about the energy necessary to reach the dynamic limit of these materials, about the nature of the design of the loading apparatus as well as the extensometer and the dimensions of the specimens, a first series of preliminary tests had to be carried out. For these information tests a special extensometer devised by the author and shown in Fig. 2, was used. The specimen a is fixed at one end b in the pendulum hammer C. At the other end the specimen supports a light transverse of fibre d, provided with two electrical contacts opposite to the micrometer screws ee' and fixed in a stiff steel transverse f in which is screwed the other end of the specimen. As the pendulum hammer swings past, this transverse f is caught on a stationary support. If higher loads than the elastic limit of the specimen are reached, the small permanent deformations are measured by the micrometer screws, giving contact with the metallic point of the transverse d and are checked by two electric lamps gg'. This extensometer was adjusted to the pendulum hammer of an Olsen 30/60 ft.-lb. capacity impact tester represented in Fig. 3, provided with a special graduated arch A to raise step-wise the striking energy of the machine and to measure by a special slide B the elastic energy of the rebounding hammer after each impact load. Based on this rebounding energy of the hammer, a certain control over the elastic and micro-plastic parts of the energy absorbed by the specimen was possible. Theoretically, the energy applied to the specimen loaded within its elastic limit should be totally regained by the rebounding hammer so that, after the impact load, it will return exactly to the same height from which it started. This is illustrated by the straight line $0a$ in Fig. 4. Theoretically, no loss of energy takes place. The rebounding angle is the same as the dropping angle of the hammer. Practically, as long as the specimen does not undergo the slightest permanent deformations, a straight line $0b$ is obtained. A smaller angle than that of $0a$ is due to friction and slight local deformation. At d, we find the important point showing the energy necessary to pass from elastic

* F. B. Seely, Resistance of Materials, page 307.

to small plastic deformation of the specimen. With still higher energy applied, the absorbed energy also becomes greater (curve O–*d*–*c*), because the dropping angle of the hammer increases at a greater rate (abscissa) than the rebounding angle (ordinate). The weight of the hammer plus that of the built-in specimen and all accessories of the extensometer was 19 lb. As illustrated in Fig. 2, the extensometer is based on the exact measurements of the displacement of one end *x* of the specimen *a*, fixed rigidly to the other end *b* of the hammer *c*. By means of a light transverse *d*, supported at the end of the gauge length of the specimen, very small elongations can be measured by two micrometer screws *e* and *e'* adjusted solidly in the loaded transverse *f* of the hammer, on which the threaded head of the specimen is fixed by a screw *h*. The electrically insulated light transverse *d* made of fibre, supports opposite to each of the micrometer screws, a metallic contact. As soon as the metallic screw touches the point of contact of the transverse the current is established and the electric lamps *g* and *g'* are lighted. By measuring the position of the micrometer screws before loading and after each dynamic load, the permanent elongation of the gauge length of the specimen can be measured to about 0·001 in. accuracy.

Four metals (steel, mild and medium, aluminium and duralumin) were investigated by this method and the results are here reported.

For the first test with aluminium and steel specimens, a cross section of 0·05 sq. in. 0·25 in. dia.) was chosen. This cross section had however, to be abandoned. Later, we used a section of about twice this value (dia. 0·375in.) as both hammers, one weighing 34¼ lb. and the other 19 lb. (magnesium alloy hammer), were too heavy for these light metal specimens, since, in the aluminium specimen, the first permanent deformation took place when dropped from a very low height. Also, the correction of a few initial, unexpected errors, such as small displacements of the machine on its foundation under heavy blows, as well as the prevention of a slow permanent deformation of the loading transverse *f* under high impact loads, were necessary. Furthermore, the fixture of the micrometers and the electrical contact wires had to be given especial care under the heavier loads.

In Figs. 5 to 12, are represented diagrams of these materials tested with the contact extensometer shown in Fig. 2. The dynamic loads are recorded on the ordinate in ft./lb. per sq. in. and per length of 1 in.; by a

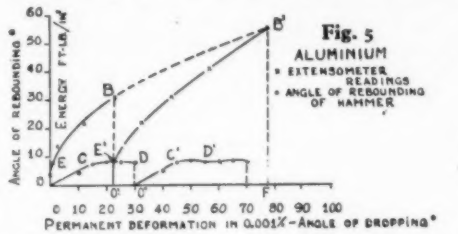


Fig. 5
ALUMINIUM
• EXTENSOMETER READINGS
◦ ANGLE OF REBOUNDING OF HAMMER

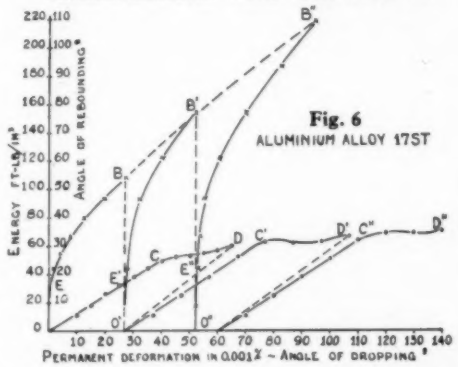


Fig. 6
ALUMINIUM ALLOY 17ST

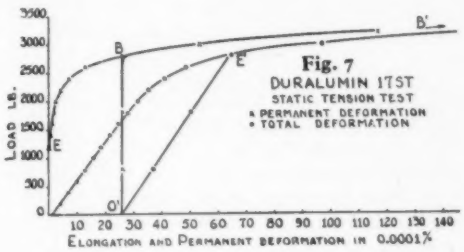


Fig. 7
DURALUMIN 17ST
STATIC TENSION TEST
▲ PERMANENT DEFORMATION
• TOTAL DEFORMATION

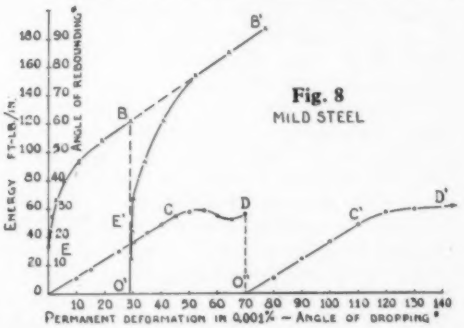


Fig. 8
MILD STEEL

TABLE II.—RESULTS OF PRELIMINARY TESTS—METHOD I.

Material	Dynamic test								Static test Diameter of specimen 0·312 in. Gauge length 3·3 in.				
	Dim. of spec. dia.	Gauge length inch	Weight of hammer lb.	Cycle of loading 1-first 2-second	E perm. def. 0·04% ft.-lb./in.³	E_1 hammer	Def. total 1/1,000 in.	Fig.	Load lb.	E lb./in.² perm. def. 0·003%	Yield strength 0·2%	Def. total 1/1,000 in.	Fig.
Aluminium	0·250	2·5	19	1	5–6	7–8	225 (31 ft.-lb.)	5	900	11,500	18,200	92	22
				2	8–10	8–9	78 (55 ft.-lb.)						
Dural 17 ST	0·375	2·5	34·5	1	30–35	45–50	27 (108 ft.-lb.)	6	1,600	20,800	40,000	173	7
				2	42	60	52 (154 ft.-lb.)						
				3	52–54	62–64	95 (220 ft.-lb.)						
Steel mild	0·375	2·5	34·5	1	40	55	29 (120 ft.-lb.)	8	2,500	32,600	41,000	99	10
				2	40–60	50–55	77 (184 ft.-lb.)						
Steel medium	0·375	2·5	34·5	1	70–80	68–70	36 (154 ft.-lb.)	9	3,000	39,000	51,500	140	11
				2	80–85	—	69 (175 ft.-lb.)						
				3	110–120	—	104 (220 ft.-lb.)						

second scale, the angle of the hammer rebound in degrees is also recorded on the ordinate. The abscissa shows the permanent deformation of the specimen in 0·001 in. per in., as well as the angle of the hammer drop in degrees. As may be seen by these diagrams, all materials tested show a distinct dynamic limit E. This limit is very low for aluminium for instance, according to Fig. 5 and Table II. Up to 4 ft.-lb. per cubic in., calculated on a unit length of 1 in., no permanent deformations smaller than 0·001 in. per in. of length could be measured on specimens of 0·25 in. dia. and using a light magnesium hammer weighing only 19 lb. Under higher dynamic loads the specimen elongated at 8 ft.-lb. per cubic in. and at about 0·001 in. per in., so that the elastic limit may be found to be about 5 to 6 ft.-lb. per cubic in. Under gradually increasing dynamic loads the deformations increase rapidly and, at about 31 ft.-lb. per cubic in., amount to more than 22½ thousandths of an in. (diagram 0–E–B). It is also interesting to note that the transition from elastic to plastic deformation of the specimen can be checked by the diagram representing the angle of rebound of the loading hammer in its function of rebounding from the height drop (diagram 0–C–D). Between 0 and C the proportion between these two angles remains the same. However, as soon as the elastic limit of the specimen is reached, this proportion changes distinctly; one part of the dynamic load is used for stretching the specimen, and the angle of rebound is smaller than the one corresponding to the elastic range of the specimen. Small permanent deformations can easily be observed by the deviation in C of the rebounding curve 0–C–D, which does not remain straight under plastic deformation of the specimen. It is evident that the value of C, due to a lower sensitivity of the rebounding pendulum hammer, is generally found somewhat higher as, in this case, 7 to 8 ft.-lb./sq. in. instead of 5 to 6 ft.-lb./sq. in., as found by the direct measuring method checked on the specimen itself.

After these first permanent deformations of 22½/1,000 in. per in. at a load of 31 ft.-lb./cu. in., the test was interrupted and the measuring instruments reset at zero. Starting immediately a second time to measure the elastic and micro-plastic properties of this same cold-stretched specimen, the dynamic elastic limit was not, as for the static test, found in the neighbourhood of the preceding maximum load. On the contrary, it was found at the lower end of the diagram which means in the neighbourhood of the first recorded dynamic elastic limit E.

In the second test, the elastic limit E of the virgin material is shifted to E′ (8 to 10 ft.-lb./cu. in. instead of 5 to 6 ft.-lb./cu. in.). This is only a few ft.-lb. higher than for E of the virgin material and represents only 30% of the maximum preceding impact load B. Also, point C′ on the rebounding diagram 0″–C′–D′ conforms fairly well to the new elastic limit E′. Furthermore, the micro-plastic part E′–B′, of the load-deformation diagram 0′–E′–B′, rises more rapidly than does E–B until point B′ is reached. Under higher loads, starting from point B′, both diagrams E–B–B′ and E′–B′, as will be shown with other materials, will follow a common curve. This is also the case for statically tested materials. In accordance with these results, it can be seen that from these two kinds of tests (static and dynamic) two conclusions may be drawn: first, the important fact becomes clear that for aluminium the elastic limit rises only very slowly with preliminary increasing plastic deformations; and, second that much greater plastic deformations 0′–F are necessary before the second load deformation diagram 0′–E′–B′ follows the curve of the original test. For static tests the permanent deformation 0′–F, or B–B′, is comparatively short. This means that this material and also other structural material, as may be shown later, is much more sensitive to dynamic than to static loads, which fact could have been shown in another investigation, as mentioned by the author in a paper discussing the influence of vibrations on the resistance of materials.[5]

In Fig. 6 are represented results of Duralumin 17 ST tested with a pendulum hammer of 34½ lb. and using specimens of 0·375 in. dia. With this alloy, as for the preceding aluminium specimens, the same fundamental observations concerning the dynamic properties of metals were made. At small impact loads no permanent deformation could be measured up to 25 ft.-lb./cu. in.; only at 35 ft.-lb./cu. in. was the dynamic elastic limit surpassed measuring 0·0005 in./in. elongation (point E). With increasing impact loads the permanent deformations increase rapidly, so that to produce 27/1,000 in./in. elongation, a dynamic load of 108 ft.-lb./cu. in. was necessary (point B). The rebounding hammer curve 0–C–D, at point C, reveals the absorption of additional energy with loads greater than 45–50 ft.-lb./cu. in.

At a second loading of the stretched duralumin the load deformation curve becomes steeper, revealing an elastic limit E′ at a loading which is smaller than 42 ft.-lb./cu. in. and somewhat greater than that at the first elastic limit of the virgin material found to be 35 ft.-lb./cu. in. The second curve of the permanent deformation reaches the values of the first diagram at point B′ with a permanent deformation of about 25/1,000 in. per in. and a total elongation 0–0″ of 52/1,000 in. per in. The rebounding diagram 0′–C′–D′ indicates the limit of elastic deformation at dynamic loads of about 60 ft.-lb./cu. in. For further information a third cycle of dynamic loadings was made with this material, represented by the load-deformation curves 0″–E″–B″ and the rebounding curve 0″–C″–D″. Here again, in conformity with the preceding results, the elastic limit E″ seems to be only slightly higher than E′, and the third loading curve 0″–E″–B″ is steeper than 0′–E′–B′. For instance, at a load of 100 ft.-lb./cu. in. a permanent deformation of about 4/1,000 in. per in. was measured, while the unstretched specimen at this load showed 23/1,000 in. per in. and at a second loading only 7/1,000 in. per in. The plastic limit C″, according to the rebounding curve 0″–C″–D″, is also somewhat higher than C′. The diagram, according to Fig. 6 in comparison with Fig. 5 representing the results of tests on aluminium, shows in an illustrative manner the behaviour of these two mechanically quite different metals with regard to their elastic and micro-plastic properties, which are of prime importance to the designer of dynamically loaded elements. The static load strain curve, showing the elastic and micro-plastic characteristics of Duralumin made with specimens (0·3125 in. dia.) of the same bar, is represented in Fig. 7. The loads are reported on the ordinate and the strain in 0·0001 in./in., on the abscissa. These records show also the permanent deformation curve 0–E–B after gradually loading the specimen up to the plastic range, as well as the behaviour of Duralumin during a second cycle of loading 0′–E′–B′. It can be seen that the elastic limit E′ at a second static loading is practically identical with

5. G. Welter. *Zeit. f. Metallkunde*, 1937, p. 60, and *Engineering*, July 2, 1937. *Génie Civil*, October 2, 1937.

the maximum preceding load at B. The prestressed material under static loads is elastic up to the maximum preceding load (line 0′–E′), where very rapid plastic deformation again starts (E′–B′) under a small load increase of this preliminary load B.

The same investigations with mild and medium steel were made dynamically, as represented in Figs. 8 and 9 and statically as shown in Figs. 10 and 11.

For mild steel an elastic limit of about 40 ft.-lb./cu. in. was measured during the first test, and at 120 ft.-lb./cu. in. a permanent plastic defomation of 29/1,000 was found. By the rebounding method the elastic limit was found to be about 55 ft.-lb./cu. in. at C. At a second trial the elastic limit E′ was found to be about the same value (40 to 50 ft.-lb./cu. in.), but

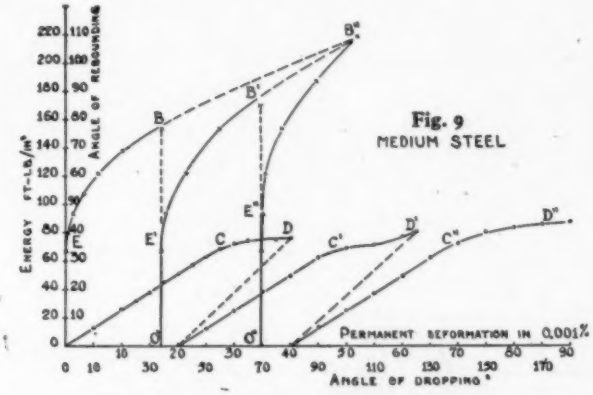


Fig. 9
MEDIUM STEEL

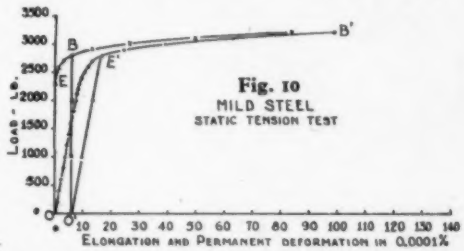


Fig. 10
MILD STEEL
STATIC TENSION TEST

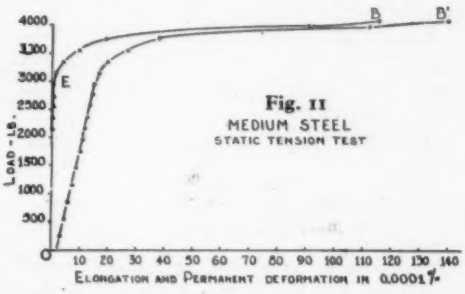


Fig. 11
MEDIUM STEEL
STATIC TENSION TEST

the dynamic loads were again growing much faster than the permanent deformations (at 120 ft.-lb./cu. in. less than half the elongation of the virgin specimen was measured), and after an addition deformation of about 23/1,000 in. per in. the curve continued the trajectory of the original metal B–B′.

Analogous results were obtained with medium steel (Fig. 9) having a dynamic elastic limit of about 70 to 80 ft.-lb./cu. in. at first trial, about 80–85 ft.-lb./cu. in. at a second trial, and over 110 ft.-lb./cu. in. at the third trial. A dynamic load of 220 ft.-lb./cu. in. was necessary the third time to attain an elongation of about 34/1,000 in. The rebounding diagrams 0–C–D, 0–C′–D′ and 0–C″–D″ are in fairly close agreement with these results. They indicate a somewhat lower dynamic elastic limit of about 70 ft.-lb./cu. in.

The dynamic test results of mild and medium steel may be compared to the static load strain curves of the same material as represented in Figs. 10 and 11, showing that the mild steel specimens have a static elastic limit of about 30,000 lb./sq. in. and about 36,500 lb./sq. in. for medium steel (Figs. 10 and 11).

This first series of tests (despite some irregularities, which as mentioned above, might have been gradually eliminated during these tests) already gives a fairly good picture of the behaviour of some materials under increasing impact loads. They have been explained in some more detail, in order that the results of the following series of tests, made with other extensometers and a different loading process of the specimens, might be presented more briefly.

The reason for making these changes has been twofold: on the one hand, the extensometer used for the information tests did not operate with sufficient accuracy, as the micro-deformations of the specimen were measured on a cylindrical gauge length which—due to the fillets between the smaller and the larger sections—was not exactly known. To avoid this difficulty a mirror extensometer of the Martens type was used, measuring—by means of a steel prism fixed between the specimen and a steel bar—the deformations on exactly the desired gauge length (2 in.) Furthermore, the Martens extensometer being one of the most sensitive and accurate instruments in existence for this kind of test, the highest precision could be expected with a modified instrument based on this principle. On the other hand, it had been observed that some of the tested specimens, having been appreciably stretched under impact loads of the pendulum hammer, were not completely axial. After the test they did not run true in the lathe their threaded heads being somewhat out of centre. This is a fundamental defect which may have some harmful effects on the values of the elastic and micro-plastic test results. This defect is intimately tied up with the principle of the pendulum impact testing machine itself. In fact, what has been observed here in connection with specimens showing small deformations also takes place in a much more harmful degree during the standardised impact tensile tests (A.S.T.M. Standards 1943, Designation E–23–41T), where under A7 it is stated that: "Such specimens (tension impact test specimens) may be tested with many of the commercial forms of the Charpy or Izod machine . . . One arrangement is to have the specimen threaded into the moving member with arrangement to have the free end of the specimen catch on stationary supports as the pendulum swings past." This is exactly what happened in this investigation and this is also why this method had to be abandoned. The loading trajectory of the pendulum being an arc of a circle, it is easy to understand that the specimen threaded into the moving member (swinging hammer), and that its free end, being caught by means of a transverse on stationary supports, followed precisely during its deformation, the trajectory of the hammer. Consequently, the specimen is pulled into an arc of a circle, so that its axis becomes eccentric with one or both threaded ends. Even if the striking transverse is provided with cylindrical, striking edges, or with loading spheres (not very effective at higher loads, as plastic deformations

and absorption of energy at the striking points are difficult to avoid) the specimens, as could be experimentally shown, are eccentric after the test. The threaded heads are more or less visibly bent, depending on the amount of dynamic elongation they have endured. Under these prescribed and standardised testing conditions (see Riehle–Olsen–Charpy–Izod testing machines) no reliable results can be obtained concerning the energy actually absorbed by the specimens while breaking (energy reported in foot-pounds and known as the impact value of the specimens). Especially brittle materials and materials with a high notch sensitivity, when tested under a single load, are unfavourably affected by this method and no reliable results can be expected. It seems that the numerous, very contradictory and sometimes confusing results, obtained by the standard tensile impact test, have their origin in this fundamental error of the testing method itself. No existing standard impact machine can give any useful results in this respect, due to the fact that no true axial loading takes place during the dynamic deformation of the specimen. This effect is especially harmful if dynamic tensile tests are made on brittle materials, such as cast iron or aluminium alloys.

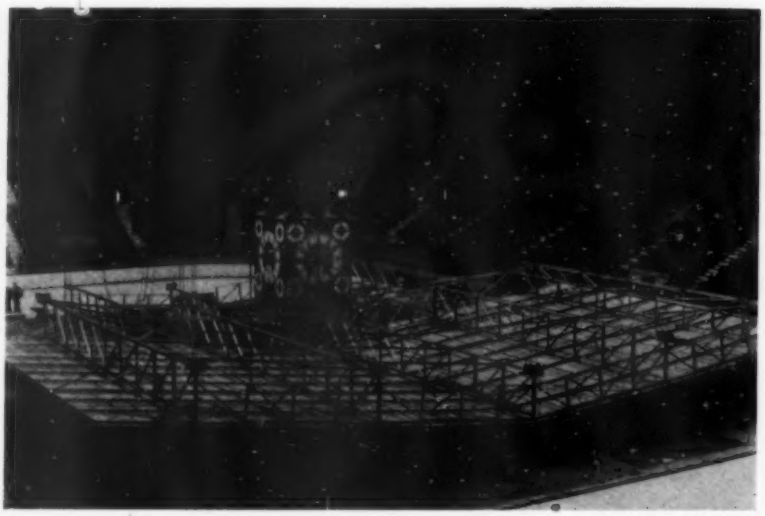
(To be continued.)

Sound Board for Harringay Arena

Aluminium Replaces a Previous Tubular Steel Structure

IN order to improve the acoustics of Harringay Arena during the time in which it is used for concerts, e.g., the London Musical Festival, it was decided to erect a sound board and suspend it over the centre of the arena, directly above the orchestra.

This sound board, measuring 104 ft. × 90 ft., has now been completed and erected. It is of interesting design and construction employing a frame-work of aluminium alloy, carrying asbestos sheeting. The framing consists of lattice girders 50 ft. span with secondary lattice girders where required to provide an opening for the central Ice hockey clock which has to pass through the sound board during the lifting operation. The structure has to be suitably braced together to form a space frame in order to allow for wracking and twisting that might take place during lifting. The framing rails on the underside of the lattice girders support small galvanised " T " bars at 2 ft. 0 in. centres which carry the flat asbestos cement sheet ceiling fixed to the framing by wooden wedges. The ends of each of the girders carry winches for lifting the complete sound board in two half units, pulleys being attached to the existing roof trusses at bottom tie level. Wire ropes are used which are anchored to the winch, taken up over the pulleys and brought back to the winch for winding on to the drum.



By courtesy of Almin Ltd.

Completed sound board ready for lifting into position by winches which can be seen in the foreground.

The framing of each half of the sound board was erected on trestles 3 ft. off the floor until the structure was complete and the winches and ropes fixed, when the unit was raised to a height of 6 ft. for the asbestos sheets to be fixed and painted. When each half of the sound board was completely assembled, it was raised to a height of approximately 46 ft. above the auditorium by operators standing at the ends and winding up the winches The actual winding operation was controlled by the use of the loud speaker system installed in the Arena. After the sound board was in position, safety bonds were fixed attaching the girders to the roof framing independent of the winches, in order to cover any possibility of failure of winches or wire ropes.

It is interesting to note that this aluminium structure replaced a previous structure in tubular steel in order to cut down the time required during erection and dismantling. This was an important consideration since the whole Arena was put out of use during these operations, involving loss of revenue, and for this reason the aluminium sound board was constructed in units which could be rapidly assembled on the site. The time taken to erect on the first occasion was 60 hours and it is thought that with practice this figure can be reduced by 20–25%. The complete weight for which the sound board structure is designed is approximately 23 tons of which the aluminium alloy structure weighs only 3½ tons.

The aluminium-alloy structure was designed and constructed by Structural & Mechanical Development Engineers, Ltd., of Slough, Bucks (a member of the Almin group), to the specification and under the direction of Dr. Oscar Faber, Consulting Engineer to Harringay Arena, Ltd.

Reviews of Current Literature

The Elements of Fuel Technology

THE subject covered by the title of this book is of great importance at the present time, since the conservation of coal is a matter of national concern, and effective measures for the purpose must be based on a sound understanding of the scientific principles at the basis of the preparation, manufacture and use of fuel. The subject of fuel technology covers not only coal and its products, but also oil, synthetic fuels, and indeed anything that it is attempted to burn with the object of obtaining heat and power. An understanding of the processes and techniques involved in this branch of technical science requires a wide range of knowledge of the fundamental sciences. Its practice contacts with that of almost every branch of manufacturing industry, and elsewhere, as typified by the fact that even the farmer has become mechanised and now requires the service of heat and power. The author faced a formidable task when he undertook to cover so wide a subject in 500 or so pages of fairly open print.

This volume has appeared at an opportune moment, for there has been some ten years halt in the normal production of major textbooks. At the same time there has been given to fuel matters a considerable impetus in the realisation of its place in the national economy. There must be therefore many potential readers in this field.

The present volume is comprehensive in objective, and there is provided an introduction to many aspects of the subject. It resembles in character the earlier volume, "Coal, Its Constitution and Uses," in which Dr. Himus collaborated with the late Professor W. A. Bone in rewriting and bringing up-to-date the original classic "Coal and Its Scientific Uses", produced by Bone in 1918. There are discernible, too, the fruits of the author's own extensive experience in the teaching of the subject. Perhaps this has been responsible for the frequent occurrence of tabular matter giving detailed comparisons such, for example, as between the different types and characteristics of steam boilers. Such tables may be unpopular with the general reader, but they are valuable to students. The book is well written, clearly printed, and having in mind the limitations of the times in regard to an admissible wealth of diagrams, reasonably well illustrated.

The book, has, however, suffered from two circumstances, one, the attempt to cover so wide a subject in one volume, and two, that the script was completed in 1943 and not in the hands of the reading public till virtually 1948. The first might not have mattered if the second could have been taken care of, for the result has been that important modern developments have perforce been excluded. There is no reference to coal as a source of liquid fuels of later origin than 1938, although in the intervening period marked advances in technique have been made both in Germany and in America. The bibliographies at the end of each chapter, usually so valuable a feature of a text book, do not give guidance to a number of the most valuable sources of detailed information. The reader interested in utilisation would have welcomed a more complete treatment of the appropriate elements of combustion, heat transmission and fluid flow.

The volume is nevertheless to be welcomed as a comprehensive treatise full of valuable information on a subject in which such a book was needed. It must accordingly appeal to a wide circle of readers. By Godfrey W. Himas, published by Leonard Hill Ltd., 17, Stratford Place, London, W.1, price 42s. net.

Failure of Metals by Fatigue

THE Proceedings of a Symposium held in the University of Melbourne in December, 1946, have now been published by the Melbourne University Press, price 42s. After a foreword by Dr. H. J. Gough, F.R.S., thirty papers submitted are reproduced, together with the discussions upon them. It is not too much to say that this volume represents the most authoritative and complete treatment of the subject of fatigue in all its ramifications, which has hitherto been published. Hardly any aspect fails to receive some consideration, and both to the practical engineer and to the theoretical metallurgist alike, there will be direct appeal. The one defect, and it may well be that it was inevitable, unless there was to be considerable delay in publishing the work, is the lack of an index. This would have added enormously to the value of the book so far as the ordinary reader is concerned.

Broadly speaking the papers may be divided into three groups, though there is inevitably overlap from one to another. There is, in the first place, the type of contribution dealing with the meaning and measurement of fatigue strength: secondly, the importance of fatigue phenomena in their practical engineering aspects, and thirdly, and in some ways perhaps the most interesting of all, papers dealing with the very outskirts of the field. To each of these groups the papers in this volume make a substantial contribution. They are, for the most part, provided with excellent bibliographies which makes it easy for a reader concerned with any one particular aspect to make contact with the work already done throughout the world. The discussions are interesting, but being almost confined to Australian metallurgists and engineers, have not got the importance that a more world-wide discussion would have provided. This is not intended in any way to belittle the value of what discussion there is. Like Oliver Twist, however, one would have liked more.

It would be quite impossible in any ordinary review to do more than mention the ground covered. The general treatment of fatigue is covered by a paper by Professor Neill Greenwood, the metallographic aspects by Professor H. F. Moore: Boas, treats of the theories of the mechanism of fatigue failure: Dr. Ulick Evans, of the electro-chemistry of corrosion fatigue: and Orr, the detection of fatigue cracks. On the practical side fatigue in aircraft is dealt with by Dr. H. Sutton, and by George, Grover, and Chalmers: fatigue tests on welded H-beams by Percival and Weeke: the design of shafts subject to fluctuating loading is dealt with by Macdonald: Ritchie considers the fatigue of bolts and studs: Osborne, of welded steel tubing: Edwards, fatigue problems in the gas turbine aero-engine: Professor O'Neill, failure of railway material, and so on, to mention only some of the papers of immediate practical significance. The last group deals with a wide variety of subjects not always recognised as of significance in connection with the general problem of fatigue. The measurement of dynamic strain by a wide variety of strain gauges, some of quite modern design; the determination of stress concentrations; photo elasticity; the measurement and effects of residual stresses of

Professor Sachs ; notch sensitivity and the influence of damping capacity in connection with telephone cables and the like, are an indication of the contents in this last section.

To everybody concerned with the production of this volume, wholehearted thanks are due from metallurgist and engineer alike. The book is essential, no other word is adequate, to all those concerned with the fatigue of metals in any of its widely varied fields. To repeat, it is published by the Melbourne University Press, and is available at 42s. net.

An Introduction to Metallurgy

THE author, Professor of Metallurgy in the University of Idaho, U.S.A., presents a general introduction to the whole field of metallurgy, both physical and process. The first half of the book is devoted to the former ; the latter to the extraction side. Such an attempt to cover the whole ground in one volume is typical rather of the American than of the British point of view, and in this country would almost certainly have been done in two separate volumes, each produced by an author with particular interests in one or other of these fields. The general content is somewhat strikingly similar to that of Liddell and Doan's " Principles of Metallurgy," and it may be an indication of advancing years on the reviewer's part that he prefers the latter to the book now under consideration.

Such an introduction must clearly appeal in the main to the comparatively young student, and it is, therefore, essential that the presentation should be, above all things, absolutely clear. There are, unfortunately, only too many examples where this is not the case. On page 38, for instance, it is stated that " a single crystallite may have several systems of slip planes intersecting one another ; within a given crystal, however, all the slip planes of any system must be parallel." This might easily be interpreted as implying that all the octahedral planes in a given crystal are parallel to each other. On page 52 the author states that the " elastic limit of the metal increases (as a result of cold-working) also, and the metal becomes ' hard and springy ' as compared with its ' soft ' condition before working." In the case of iron and steel, at any rate, this is demonstrably untrue. Working *reduces* the elastic limit and the increase is found only after subsequent ageing.

The author makes a praiseworthy attempt to link the more theoretical aspects of his subject with their practical implications. One is, therefore, all the more surprised to find on page 84 that " magnesium metal is used in flares, fireworks and incendiary bombs because it burns at a high temperature with the evolution of large amounts of heat and light." Surely, there are other uses for this metal sufficiently significant to have deserved mention.

On page 161 it is stated that " in two-phase alloys the hardness of any alloy is an average of the hardness of the two constituents." Would a student be seriously blameworthy if he interpreted this statement as meaning, for instance, that all 0·9% carbon steels in the unhardened condition have the same hardness ? One could point to many statements of this kind which are, to say the least, open to criticism.

In the second and rather larger section of the book dealing with the different types of process metallurgy, the author gives a good summary of the general principles involved. Here again, however, there are mistakes. On page 205 it is stated that " it is difficult to remove (sulphur) in the refining operation." On page 206, on the other hand, we find that " sulphur can be removed in the basic open hearth, and all the important elements can be secured in the desired percentages." There is clearly some discrepancy here. On page 217 we find the statement, " manganese in steel usually takes the form of Mn_3C, manganese carbide or $(Fe, Mn)_3C$, manganiferrous cementite, and at high temperatures the manganese is in solution in austenite." If there is one thing which is quite certain it is that at *ordinary temperatures* manganese is still partly in solution in the ferrite. The evidence for this is overwhelming. In Table I (page 469), figures for the equilibrium tensions of some sulphates have been reproduced. These were, in the first instance, taken from Schenk, and it is not made clear that the tension was not due to sulphur-trioxide alone, but was the sum of the sulphur-trioxide tension and that of its decomposition products.

Despite these blemishes, however, the book does cover the ground that it set out to consider, quite well, but probably no better than, if as well as, other attempts which have previously been made.

By Joseph Newton ; 2nd Edition, 1948, 645 pp., published by Chapman & Hall, Ltd., 37, Essex Street, London, W.C. 2, price 33s. net.

Index to 1947 A.S.T.M. Standards

This index is an adjunct to the book of American Society for Testing Materials standards and comprises a ready-reference for locating any A.S.T.M. standard in the bound publication of the Society in which it appears. It will also be of service in ascertaining whether the Society has issued a standard on a specific subject. The index covers all the current standards in five parts of the 1946 Book of A.S.T.M. Standards and its 1947 Supplement as well as the standards published in the 1946 Book of A.S.T.M. Methods of Chemical Analysis of Metals. References are also given to the current " Tentative Revisions " of Standards.

Copies of this 240-page publication are furnished without charge on written request to A.S.T.M. Headquarters, 1916, Race Street, Philadelphia, Pa., U.S.A.

Hints on Steel

WRITTEN in non-technical language, as a handy reference for the man who is buying and using steel, " Hints on Steel," published by Sanderson Bros. and Newbould, Ltd., has now reached its Ninth Revised Edition. The first quarter of this 136-page booklet is taken up with notes on heat-treatment and testing, and on technical terms used in connection with steel. Apart from a number of useful engineering tables at the end, the remainder of the book details the various special tool, die and other steels made by the company. Full particulars of heat-treatment are given, and in many cases the nominal composition is stated. A feature of the information on the Company's versions of the various En specifications, is the inclusion, in appropriate cases, of the test results obtained by tempering at various temperatures. Well-bound and of handy size, this booklet should prove of value to those for whom it is intended.

Copies may be obtained from the publishers, Sanderson Bros. & Newbould, Ltd., Attercliffe Works, Sheffield.

Mechanical Properties and Welding Characteristics of Single Projections in Low Carbon Mild Steel; with Particular Reference to the 14 S.W.G. Thickness

AS a rapid and efficient mass-production process for the fabrication of light engineering components in mild steel, projection welding is now well established. Its application spread widely during the war, particularly in the manufacture of small arms and bomb tails. Previous to the B.W.R.A.'s programme of research, now well under way, the process had not received any exhaustive fundamental examination. This report,* by Mr. A. J. Hipperson, for the FR. 3 Committee (on Projection Welding of Steel) of the British Welding Research Association, marks the completion of the first phase of the work, and the investigation has been carried out in order to attempt to relate the values of the welding variables with the strength and quality of welds produced, and ultimately to put forward recommendations as to methods for obtaining optimum results.

Although joints containing only one projection weld are rarely made in practice, it was first necessary to investigate the formation of single welds in order that a firm foundation could be established on which to base the experimental work on joints containing more than one projection. Where single welds are required, spot welding would normally be used, and the advantage of projection welding essentially lies in the fact that many welds may be made in one cycle of operations of the welding machine.

The work described in the report covers the preliminary experiments on single projections, and it has been possible to put forward optimum conditions for producing such welds. It includes a study of the effects of short circuit secondary current, duration of current, and applied pressure—the main variables involved—and also of many subsidiary variables. Records have been taken of the behaviour of the projection at room temperature under load, so that an assessment of the rigidity of the projection could be made. Welds produced under controlled conditions have been carefully examined for strength, size and consistency, and the effect of each variable upon these factors has been determined. Many difficulties not previously apparent have been brought to light, and methods for effecting possible improvements in the process have been suggested. The greatest difficulty would seem to be the lack of forging pressure, which occurs after collapse of the projection. This tends to produce slight cavities and porosity at the original sheet interface and, generally speaking, the welds are not quite so well consolidated as spot welds.

One of the most interesting and important features of the results of the work is the high degree of consistency in weld strength that can be obtained from single projection welds, provided certain optimum values of the welding variables are used. A maximum scatter in the strength of welds, made under the optimum conditions established, was found to be—3%. At least half of this scatter was accounted for by variations in line voltage during the welding tests.

The actual stages in the formation of projection welds have been examined, and a group of macrophotographs has been taken of sections of welds made at a constant welding current setting and electrode pressure, but at various welding times ranging from 1 cycle to 50 cycles. It is clear from these tests that weld nugget formation starts relatively slowly, and the presence of a cast nugget as such is not obvious until after complete projection collapse has occurred. Following this, the weld size increases indefinitely with time, the longer time tending to produce cavities at the original sheet interface. Close contact of the fraying surfaces around the weld has been obtained, and by reason of the fact that large flat electrodes were used, complete freedom from surface indentation was apparent

The experiments are now to be extended to a wider range of sheet thicknesses, and to the welding of studs and bosses to sheet; and the results of the present tests provide the lead required for investigating the formation of multiple projection welded joints.

* Welding Research Supplement to the Transactions of the Institute of Welding, Aug., 1948.

International Scientific Film Congress

THE Second Congress of The International Scientific Film Association will be held in London from October 4th to 11th, 1948.

The Association was constituted last year in Paris by delegates from 22 countries who had accepted the joint invitation to the Inaugural Congress from The Scientific Film Associations of Great Britain and France. The primary aim of the Association is:

> "To raise the standard and to promote the use of the scientific film and related material throughout the world in order to achieve the widest possible understanding and appreciation of scientific method and outlook, especially in relation to social progress."

This year's Congress is being convened by The Scientific Film Association of Great Britain, with the help of The British Film Institute, and invitations have already been issued to countries throughout the world. The Congress will open with a formal reception to the delegates on October 4th, and the following three days will be devoted to business meetings of The International Scientific Film Association. On October 8th, 9th, and 10th, there will be a Festival of Scientific Films, when it is hoped to show many contributions from all the participating countries to members of the general public.

The widespread public interest in this country in the scientific film as evidenced by over 10,000 members of local scientific film societies, the introduction of scientific films and other visual aids into the educational programme in this country and, in particular, the many pioneer activities of The Scientific Film Association with its country-wide membership makes it particularly appropriate that this Congress should be held in Great Britain. Visitors from overseas will have an opportunity of studying the many contributions which this country has made by the use of scientific films.

Further details may be obtained from The Scientific Film Association of 34, Soho Square, London, W. 1.

Staff Changes and Appointments

THE RT. HON. THE VISCOUNT RIDLEY has joined the Board of Head, Wrightson & Co., Ltd.

MR. F. A. YOUNG, Northern representative of Messrs. E. H. Jones (Machine Tools), Ltd. for the last 14 years has joined the Rockwell Machine Tool Co., Ltd., as representative for the Northern area. Mr. Young will be located at offices opened by the Company at 39, High Street, Stockport. (Tel. : Stockport 3077).

MR. A. PREECE has been appointed Professor of Metallurgy at Durham University, in succession to Professor C. E. Pearson.

MR. W. M. SERVICE, previously works manager and a special director of Messrs. Wm. Beardmore & Co., Ltd., has joined the Board of Messrs. Mechans, Ltd., Glasgow, as technical director.

COLONEL ALAN STEIN, of John Stein & Co., Ltd., Glasgow, has been appointed to the Scottish Regional Council of the Federation of British Industries.

MR. NORMAN F. DUFTY, who left England some time ago to join the Agloma Steel Corporation, has now returned to this country as works metallurgist with Messrs. William Jessop & Sons, Ltd., Sheffield.

MR. J. R. MIDDLETON-WALKER has resigned his position of works manager to the Steetley Company's Conisborough Works in order to devote his full time to the business of C. F. Harris, Ltd., the controlling interest in which he recently acquired.

The Woodall-Duckham Vertical Retort and Oven Construction Co. (1920), Ltd., announces the following changes in the management of the company, with effect from July 1st, 1948.

MR. F. B. RICHARDS, whilst retaining the chairmanship of the company, has relinquished his position as a joint managing director.

MR. G. J. JACKSON will continue as a joint managing director until his retirement from the board at the end of this year. Arrangements have been made to retain his services after that date in a part-time consultative capacity. Mr. Jackson will retain his seat on the Board of the parent company, Messrs. Woodall-Duckham (1920), Ltd.

MR. J. S. JEFFREY and MR. D. RIDER have been appointed joint managing directors.

MR. T. C. FINLAYSON is now deputy-chairman.

MR. FRANCIS D. BRIDGE has left Messrs. Wm. Beardmore & Co., Ltd., Glasgow, to join the staff of Messrs. Guest Keen & Nettlefolds' Research Laboratories, as senior research officer in their Metals Division.

DR. N. SWINDELLS has joined Messrs. McKechnie Brothers, Ltd., Birmingham, as chief metallurgist.

MR. ROBERT M. PARRY, managing director of the British Driver-Harris Company, Ltd., manufacturers of the well-known range of " Nichrome " resistance materials, has been elected to the Board of the Irish Driver-Harris Company, Ltd., whose Head Office is in Dublin.

MR. E. W. SANGER relinquished his position as general sales manager of the Birmingham Aluminium Casting (1903) Co., Ltd. (Birmal) to take up an appointment as joint managing director of Begwaco Meters, Ltd., at Farnworth, Lancs. Mr. Sanger will be succeeded by MR. W. J. PRICE, formerly Sales Engineer of " Birmal."

Metallurgists Refresher Course

THE second Refresher Course arranged by the Institution of Metallurgists will be held at Ashorne Hill from Friday, October 1st to Sunday, October 3rd, 1948.

This year's course will be concerned with the mechanical working of metals, and the various aspects of the subject will be dealt with by experts in each field.

Dr. E. Orowan will open the proceedings with a paper on " The Mechanical Deformation of Metals," on the Friday evening. On Saturday, Dr. L. B. Pfeil will deal with " The Removal of the Effects of Mechanical Working," Dr. Hugh Ford with " Rolling," and Dr. R. Genders with " Extrusion." The technical sessions will conclude on Sunday morning with two papers on cold-working, " Deep Drawing and Pressing," by Prof. H. W. Swift, and " Cold Drawing," by Prof. F. C. Thompson.

Liverpool Metallurgical Society

THIS recently formed Society has arranged a very interesting programme for its first session which begins on October 7th, when Prof. J. H. Andrew, D.Sc., will lecture on the topic, " New Lamps for Old." On November 11th, which is a joint meeting with the Society of Chemical Industry, Dr. N. P. Inglis will review steels used in the chemical industries. On December 1st there will be a joint meeting with Liverpool Engineering Society, at which Mr. L. W. Johnson, M.Met., will discuss " The Correlation of Metallurgical Research and Development with Engineering Requirements." Sir Charles F. Goodeve, O.B.E., D.Sc., F.R.S., at the first meeting in 1949, on January 6th, will lecture on " The Steel-making Process." Mr. F. D. Waterfall, F.I.M., on February 3rd, will discuss " Metallurgical Developments connected with Heat-treatment of Steels in Salt Baths." On March 3rd, Dr. C. J. Smithells, M.C., will discuss " The Practical Significance of Solution and Diffusion of Gases in Metals," which will be illustrated by colour films. The session will end on April 7th, when the annual general meeting will be held, in additon two films will be shown : ' Steelmaking" and "A Story of Copper." Except for the meeting on November 11th, which is to be held at Liverpool University, Brownlow Hill, and that on January 6th, which will be held in Chester, all meetings are to be held at the Liverpool Engineering Society's Rooms, 9, The Temple, 24, Dale Street, commencing at 7 p.m.

The Committee is to be congratulated on arranging such an imposing programme and they are justified in believing that all interested in metallurgical progress, will assist to ensure its success. The Hon. Secretary is Mr. C. W. J. Gellatley, 7, Woolacombe Road, Liverpool 16.

Mullard Readership in Electronics

THE Mullard Company's recognition of the necessity for industrial organisations to accept some measure of responsibility, and to assist actively in the problems of the future education of electrical engineers, has prompted them to take practical steps in this connection by offering to finance a Readership in Electronics at the City and Guilds College of Imperial College.

Following discussions with Professor Willis Jackson on this subject an approach was made to the Rector of Imperial College, Sir Richard Southwell, outlining the Company's views and desires, and this has resulted in the authorities of the University of London accepting the offer made by the Mullard Company.

MICROANALYSIS

CHEMICAL AND PHYSICAL METHODS

APPARATUS METALLURGICAL APPLICATIONS TECHNIQUE

"A GOOD analytical chemist must be an organic chemist, an inorganic chemist, a physical chemist, and at times a biochemist, a metallurgist, a physicist, and a specialist in several other fields." That we heartily agree with this quotation is our excuse, if excuse is needed, for including in this section from time to time articles on topics which at first sight seem to be of interest only to the organic chemist. It might be unkind, in this context, to say that in our experience the lion can be beholden to the mouse, but our meaning will be clear if we stress that no slur on the organic chemist is intended. In other words, help in our problems often comes from unexpected quarters, and the analytical chemist must often find himself indebted to the biochemist or the organic chemist for methods without which his problems might remain unsolved. Anyone familiar with the two fields of microchemistry and biochemistry, for example, will be well aware how often these have borrowed from each other. We well remember how, after a demonstration of inorganic micro-methods, we were gratified, though not unduly surprised, to be told by a biochemist that one of our simplest methods had resolved one of his most persistent headaches. Consequently, we feel that analytical chemists, even if exclusively or almost exclusively concerned with metallurgical analyses, may be interested intrigued, and perhaps (we dare hope) helped by a review of methods which up to the present have been applied almost without exception to the analysis of organic materials.

Bomb Methods in Microchemistry

Part I.—Methods for the Determination of Halogens

By J. H. Beaucourt

Bomb methods offer a rapid and convenient means of determining the halogens. They possess many advantages, and are particularly useful in series determinations. The methods available are reviewed.

THE use of bomb methods in microchemistry has received increasing attention during the last decade. They have many advantages over alternative methods. The same apparatus can be used for the determination of several elements, the process is extremely rapid and the apparatus lacks the fragility normally associated with micro and semi-micro apparatus. Whilst further experience can only decide the limitations of the process, there is little doubt that it can be used with confidence for most types of organic compound. Originally developed for determining the halogens, the process has since been extended to include the determination of sulphur, phosphorus and arsenic.

A micro method for the determination of the halogens was first developed by Elek and Hill.[1] The bomb consists of a cup 25 mm. deep, internal diameter 13 mm. and a wall-thickness of 1·5 mm. This cup is sealed by a lid fitted with a rubber gasket and held in position by a clamp. An eyelet is provided at the base of the cup to facilitate removal of the cup from the beaker in which the extraction after ignition is carried out. The bomb is constructed of stainless steel and the inside of the cup is plated with platinum to resist corrosion.

30 mg. of a mixture of pure potassium nitrate and cane sugar in the proportions of 3 : 1 is placed in the cup and the sample (about 5 mg.) is placed on the surface. 1·5 g. of sodium peroxide are added, the lid is fastened and the contents of the bomb mixed by shaking. The bomb is then tapped gently on the bench to bring the mixture to the bottom of the cup. The bomb is either gripped in a pair of tongs or held by a wire passed through the eyelet and held in the hot region of a good bunsen flame. Care must be taken not to heat too long, otherwise the rubber gasket will decompose. The reaction will be complete in about 10 secs. but it is advisable to heat for a further 5 to 10 secs.

After allowing the bomb to stand for one or two minutes, it is cooled under the tap and the lid removed. The underside of the latter is washed and the washings collected in a " Pyrex " test-tube, 25 × 200 mm. 10 ml. of hot distilled water are then introduced in the test-

1 Elek and Hill, *J.A.C.S.*, 1933, **55**, 2550.

tube and the cup immersed until the mass has dissolved. The cup is removed by a wire threaded through the eyelet, and washed. After cooling the solution by placing the test-tube in ice water, 5 ml. of concentrated nitric acid are added and the solution is filtered into another test-tube. 2 ml. of 5% silver nitrate are added and the test-tube is immersed in a boiling water-bath. 100 mg. of finely powdered hydrazine hydrate are then added to reduce bromates and iodates. Although this addition is not necessary when chlorine is being determined, as chlorates are not formed, it is best to add it as a routine operation for all cases. The precipitate is coagulated by heating and filtered on a Pregl filter ; after washing and drying the precipitate is weighed.

Liquids are sealed in thin walled capillaries ; these are opened before the bomb is sealed in the case of non-volatile liquids.

In the same year that Elek and Hill described their micro-method for halogen determination using the bomb, Beamish[2] described a semi-micro-method. He was, however, unable to get consistent results on the micro-scale. Stainless steel and nickel bombs were tried, but nickel was found to be the most suitable material. The solutions from the nickel bomb were always water-white and much less corrosion occurred. After 10 fusions the stainless-steel bomb lost 92·4 mg. whereas the nickel bomb only lost 6·7 mg.

The bomb has the same dimensions as the Elek-Hill bomb and is sealed in the same manner, using a rubber gasket.

For the determinations on the micro-scale, 0·5 g. of sodium peroxide and 10 mg. of lactose were used, but as already mentioned, the results were not satisfactory. For the semi-micro determination, sufficient sample to give 25 to 40 mg. of silver halide is taken, 1·5 mg. of sodium peroxide and 30 to 40 mg. of powdered lactose are added and, after sealing the bomb, the contents are mixed. The bomb is then heated in a flame for 30 secs., cooled first in air and then in water, and unsealed. The mass is extracted as in the Elek-Hill method, acidified and filtered using a 10 ml. Gooch crucible padded with filter paper. Silver nitrate is added, and the precipitate filtered through a 10 ml. Gooch crucible using ethanol to assist in the transference. After drying at 140° C., the precipitate is weighed.

In the case of iodine determinations, a few ml. of a saturated solution of sulphur dioxide are added, prior to the nitric acid. If iodine is liberated when the nitric acid is added, more sulphur dioxide solution is added rapidly. The determination is then completed as for chlorine and bromine.

Liquids are weighed in glass bulbs and covered with the mixture. Good results are obtained without breaking the bulbs and mixing.

Elek and Harte[3] have also described an alternative method for completing the determination of iodine. Three to six mg. of material are combusted in the bomb using their earlier procedure. The mass is dissolved in 15 to 20 ml. of water in a 125 ml. Erlenmeyer flask. The solution is boiled for 30 mins. to destroy peroxide, alundum of grain size 16 being added to overcome bumping. The solution is cooled, made just acid to methyl orange with 3N sulphuric acid and filtered into a 125 ml. Erlenmeyer flask fitted with a ground stopper. One ml. of bromine water is added and after five mins. the excess is destroyed with formic acid. Most of the iodine will be present as iodate after the combustion, but the bromine water ensures complete conversion. 0·2 to 0·3 g. of potassium iodide are added and after five mins. the liberated iodine is titrated with 0·01N sodium thiosulphate. The method is capable of high precision thanks to the six-fold amplification of the iodine.

Another semi-micro procedure for determination of halogens has been advanced by Peel, Clark and Wagner.[4] The bomb used was bought commercially. It has a capacity of eight ml. and is constructed of 98% nickel or 30% nickel steel. The cover consists of 98% nickel or nickel-plated brass. Stainless steel, Ilium or other chromium alloys were found unsuitable. The bomb is sealed by a lead gasket.

These investigators found that the Volhard method was not suitable for completing the determination. The volume and concentration require that solutions of a strength not lower than 0·02N be used, and the effective titration is small, especially for bromine and iodine. Adsorption indicators were not tried since the high salt concentration would interfere.

If the residue, after preliminary filtration of the extracted mass is dark, extraction with dilute nitric acid is essential, since it may contain some metallic compound (from the bomb) containing halogen.

In chlorine determinations a preliminary filtration of the alkaline solution is unnecessary ; since chlorate is absent the solution may be acidified before filtration. For bromine and iodine determinations, it is necessary to add either silver nitrate or the reducing agent before the solution is acidified. When silver nitrate is added to the alkaline solution, the bromine results are irregular, although the iodine figures are unaffected. The bromine figure is high and the precipitate is discoloured after acidification, suggesting contamination. In the case of iodine the initial precipitation of silver iodide is small, most of the iodine being present as iodate. The bulk of the iodine precipitates later from acid solution, so contamination is slight.

In order to have a single procedure available, reduction of bromate and iodate in alkaline solution was tried. Hydrazine reduces bromate in hot alkaline solution, but iodate requires a longer heating period since a relatively larger amount is present. Using this procedure the silver nitrate is added after acidification.

When liquids contained in glass ampoules were analysed, silica fusion took place and silicic acid precipitated when the solution was acidified. This was overcome by using gelatine capsules 5 × 15 mm. in size. However, the investigators consider that the bomb method applied to liquids is limited in application, for there is no certainty that some compounds are decomposed completely. The addition of ethanol to the capsule assists decomposition and eliminates loss of volatile liquids.

The method finally developed by Peel, Clark and Wagner is as follows : Sufficient sample to give 20 to 50 mg. of silver halide and 0·2 g. of potassium nitrate is added to the bomb. Enough sucrose to bring the total amount of organic material to 0·2 g. is added and 4·0 g. sodium peroxide. The contents of the bomb are mixed as described in the previous methods. For the analysis of liquids, 0·2 g. of potassium nitrate, 0·16 g. of sucrose and 4·0 g. of sodium peroxide are mixed in the bomb

2 Beamish, *Ind. Eng. Chem.* (An. Ed.), 1933, **5**, 348.
3 Elek and Harte, *ibid*, 1937, **9**, 502.
4 Peel, Clark and Wagner, *ibid*, 1943, **15**, 149.

and the sample added in a gelatine capsule. Without further mixing the bomb is heated in the flame of a blast lamp behind a safety screen. The flame is placed one cm. below the bomb for 15 secs. and allowed to touch the bottom for 30 secs. When cool the underside of the cover is washed into a 125 ml. beaker, the cup placed inside the beaker and sufficient water added to bring the contents to 25 ml. When the mass has dissolved the cup is removed with a glass rod and washed. The solution is heated to destroy sodium peroxide.

Ten ml. of concentrated nitric acid are added to the solution in the case of chlorine determinations; for bromine and iodine one g. of hydrazine sulphate is added and the solution stirred until the reducing agent is dissolved. The solution is then heated below boiling until effervescence ceases; this requires one hour for iodine and somewhat less for bromine. Acid is then added and the solution filtered. Five ml. of 1·7% silver nitrate are added and the precipitate filtered on a 10 ml. Gooch crucible. After washing with 1 : 100 nitric acid, the precipitate is finally washed with ethanol and ether. It is then dried to constant weight.

Clark[5] has described similar procedures to the foregoing but also includes titrimetric finishes. He states that the method fails for bromine although it is satisfactory on the macro-scale. The bomb consists of a cup 14 mm. × 30 mm. 20 to 25 mg. of sample is introduced into the bomb and covered with one g. of a mixture of sodium peroxide, potassium nitrate and sucrose in the proportions of 10 : 1·2 : 0·45. Chlorine is determined either gravimetrically or titrimetrically. If the former is preferred, the process is similar to the methods already described, the precipitate being collected on a Pregl filter. In the titrimetric process an excess of standard silver nitrate is added and the solution filtered. Two ml. of starch indicator and an amount of a saturated aqueous solution of iodine corresponding to one-fifth of the filtrate is added. The solution is then titrated with a standard potassium iodide solution until a permanent blue colour appears. In the case of iodine the solution is reduced with sodium sulphite and oxidised with bromine to convert to iodate as in the Elek-Harte method. The determination is completed in the usual way.

MacNevin and Baxley[6] have developed a different type of bomb from those hitherto described for the determination of chlorine. Their procedure is based on the classical lime fusion method and, since the pressures involved are much lower than in the sodium peroxide method, a much simpler type of bomb is required. It consists essentially of a hollow cylinder made from cold-rolled steel about three in. long and 0·5 in. external diameter. The open end is sealed by a threaded collar and a screw plug which are made of brass and are standard products. A soft copper disc is placed in the neck of the bomb as a seal. Cold rolled copper is softened by heating nearly to redness and then quenching in water.

One-third of the bomb is filled with lime, and sufficient sample to give not less than eight mg. of silver chloride is added. More lime is added until the vessel is two-thirds full. After assembly the bomb is heated for 20 mins. behind a safety screen. The contents are shaken into 50 ml. of water contained in a beaker and the bomb interior well washed with hot water. After acidifying and filtering through paper to remove carbon particles, the chloride is precipitated with silver nitrate and filtered on a Gooch micro-crucible.

When the carbon-chlorine ratio is high, it is difficult to convert all the chlorine to ionic chloride, but the addition of 100 mg. of potassium nitrate overcomes this difficulty. It should always be used when unknowns are being analysed.

In a further paper MacNevin and Brown[7] describe the application of the method to the determination of bromine and iodine. An improvement to the bomb construction is achieved by providing the contact face of the bomb chamber with a sharp ridge 0·5 mm. in height, which embeds into the copper washer to give a tight seal. To test for leaks, the bomb is half-filled with dry ice and placed in warm water. Bubbles indicate that the apparatus is not leak-proof.

The method is similar to the chlorine method except that provision is made for the possible formation of bromate and iodate. 200 mg. of hydrazine sulphate are added to the water suspension of the ignition product and the latter is warmed at 75–80° C. for five minutes. The determination is then completed in the same way as the chlorine determination.

Bomb methods for the determination of halogens appear to have achieved some popularity in Germany[8] during the war. The bomb is sealed by a separate clamp and an aluminium washer is used. A number of bombs are heated simultaneously in a thick-walled oven heated by a bunsen burner. The determination is completed by potentiometric titration. A large number of determinations may be run in a single working day using this procedure.

5 Clark, "Semi-micro Quantitative Organic Analysis," Academic Press Inc., New York, 1943.

6 MacNevin and Baxley, *Ind. Eng. Chem.* (An. Ed.), 1940, **12**, 299.

7 MacNevin and Brown, *ibid*, 1942, **14**, 908.

8 B.I.O.S., Final Report, No. 1606, Item No. 22.

An Improved Micro-Pipette

By P. F. Holt, B.Sc., Ph.D.

A MICRO-PIPETTE previously described[1] consists of a bulb or tube closed at either end by capillaries and held in a specially designed suction apparatus. The difficulty in draining this pipette, which is occasionally encountered if a drop of liquid forms across the narrow tube connecting the pipette with the suction bottle, is entirely eliminated by a modification shown in Fig. 1.

A small glass cap, *a*, made by cracking off the bottom of a test-tube, is closed by a two-hole rubber pad about 5 mm. thick sliced from a rubber bung. One hole serves to hold the pipette. The cap is supported on an S-shaped tube of 6–7mm. bore, one end of which is pushed into a hole of the pad, the other into one hole of a two-hole rubber bung which is inserted into the mouth of a small bottle, *b*. The second hole of the bung carries a glass tube with a small hole, *c*, blown in the wall, closed at its outer end by a rubber teat. If the hole is closed by the tip of the first finger, air may be forced out of the apparatus or if open, the inside pressure becomes atmospheric.

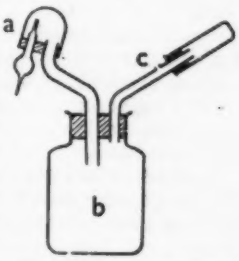


Fig. 1.—An improved micro-pipette.

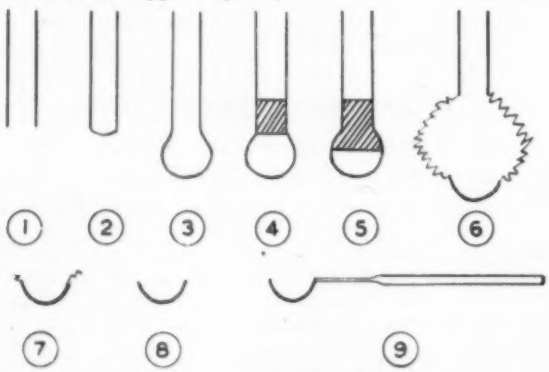
1 Holt, P. F. and Stringer, D. G., *Metallurgia*, 1948, **38**, 65.

The pipette is filled when the teat is compressed, then released with the air inlet closed and the tip of the pipette beneath the surface of the liquid. Excess liquid flows from the pipette into the outer tube and drains into the bottle. The flow of liquid is immediately checked if air is allowed to enter the bottle by opening the air inlet when, provided the delivery end is withdrawn sharply from the liquid, the pipette remains completely filled to the tip of each capillary. The liquid is delivered by applying pressure with the teat whilst *c* is closed until the upper capillary is emptied, then, with the lower capillary tip touching the side of the vessel and with *c* open, the liquid flows out until the meniscus reaches the lower capillary. A further ten seconds drainage time is allowed after which the residue of liquid filling the capillary is pushed out by closing *c* and gently compressing the teat.

A Simple Method for the Construction of Glass Spoons for Microchemical Analysis

By A. J. NUTTEN and A. MCLAREN

GLASS spoons, originally introduced by Belcher[1] for rapid evaporations on the micro-scale, have since found other uses. In qualitative inorganic microanalysis certain separations can be best effected using a number of spoons in series, and it is sometimes convenient to use them for identification tests.[2] They may also be used in preparative organic chemistry, for selecting the best crystallising solvent—the mother liquor being drawn off with a hair-tipped capillary.[3]



The method described by Belcher for their construction demands a sharp glass knife so that a deep notch is made on the bulb. Otherwise the casualty list amongst bulbs is high and perhaps only one out of six bulbs may survive the various steps in the construction to provide a suitable bowl.

The method about to be described avoids the use of a glass knife and provides a rapid means of making the bowls without risk of breakage.

Method of Construction

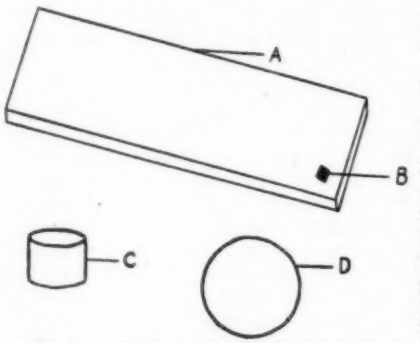
A piece of glass-tubing (1 in diagram) is sealed at one end (2) and a bulb blown (3). The tube immediately above the bulb is then heated to red heat (4), the latter stages of the heating including the top half of the bulb (5). This heated portion of the tube is then blown out till the glass is of papery consistency (6). A glass hemisphere (7) is obtained by removal of the thin glass, and its edge smoothened (8) by rotation on a glass-carborundum plate. Fusion of a suitable glass handle gives the completed spoon (9).

1 Belcher. *Metallurgia*. 1944, **30**, 280.
2 Belcher & Wilson. "Qualitative Inorganic Microanalysis." Longmans', Green, London, 1946.
3 Wilson. "Introduction to Microchemical Methods." Methuen.

The Separation of Mercurous Mercury in Qualitative Micro Analysis

By A. J. NUTTEN

IN Schoorl's method for the separation of the silver group on a microscope slide, the mercurous mercury is separated from the silver and lead by sublimation of its chloride. The mixed chloride precipitate on the slide is formed into a compact mass which is then heated carefully above a micro flame. The mercurous chloride sublimes and the sublimate is collected on a second slide where it is identified by its reaction with a solution of ammonia. Using truly micro quantities for the separation, the Schoorl method requires a certain degree of skill, and students often find difficulty in collecting the sublimate on the second slide. Thus collimation of the mercurous chloride vapour stream is difficult, resulting in the formation of a rarified sublimate which may be scarcely visible. Further, the proximity of the collecting slide to the micro flame necessarily increases the temperature of the slide and this acts as a deterrent to sublimate formation.



The following simple procedure eliminates these disadvantages of the Schoorl method :—

On a glass microscope slide, A, containing the mixed chloride precipitate, B, place a collar C, which is simply a 0·5 cm. length of ½-in. glass tubing. On top of this collar place a microscope coverslip D, on the upper surface of which is placed a small drop of water or a small piece of wetted filter paper. Sublimation is then carried out and the sublimate collected on the lower surface of the coverslip. The sublimate is then identified by the usual procedure.

International Nickel Interim Statement

THE report for the six months ended June 30th, 1948, issued by The International Nickel Company of Canada, Ltd., shows a net profit, in terms of U.S. currency, of $20,235,006, after all charges and preferred dividend requirements, equivalent to $1·32 a share on the common stock.

This compares with a net profit of $16,460,339, or $1·06 a common share, for corresponding period last year.

Net profit for the quarter ended June 30th, 1948, was $9,819,301, equal to 64c. a share, compared with $10,415,705, or 68c. a share, in the first quarter of 1948.

Unappreciated Advantages of Modern Grey Iron

By Frederick G. Sefing

THE outstanding properties of grey iron, which are an improvement over those of steel, are resistance to wear and galling, improved resistance to corrosion by water and by heat, less tendency towards warping under heating and cooling, increased capacity to dampen vibration, high notch-fatigue, compression and torsional strength and finally, low cost of forming and very good machinability. On the other hand, there are some properties which are definitely lowered by the presence of graphite, notably, a reduction in tensile strength, reduced stiffness or modulus of elasticity, and a low order of toughness.

The high-mechanical properties of the better grey irons can be obtained by alloy additions and without the need for heat-treatment. In general, the strength of grey iron, which is normally of the order of 20,000 to 30,000 lb. per sq. in., can be raised to the region of 40,000 to 70,000 to 90,000 lb. per sq. in. by the addition of from 1 to 4% of suitable alloying elements such as nickel, chromium, molybdenum, vanadium and copper. Furthermore, these high-strength irons show improvements in many properties other than strength.

Marked improvement in corrosion resistance can be achieved with rather heavy additions of from 20 to 35% nickel. This group of irons, known to the trade as "Ni-Resist" is as different from grey iron as the austenitic 18–8 stainless steel is from plain carbon steel. The corrosion rates of Table I show some of the outstanding differences between these high-nickel-irons and grey iron.

TABLE I.—COMPARATIVE CORROSION RATES.

	Nickel austenitic cast iron	Ordinary cast iron
Bad boiler water (203° F.) ..	1	6
5% sulphuric acid (cold) ..	1	475
5% hydrochloric acid (cold) ..	1	107
Sea water	1	5
Hot caustic soda	1	8

From *Mechanical Engineering*, August, 1948, pp. 667-670, 674.

Engineering Applications of Grey Iron

Some outstanding examples are given of engineering applications of grey irons which do a job that it would be relatively difficult to do with any other form of low-cost metal. These are arranged in three groups, the first of which requires resistance to wear as the outstanding property. Piston rings for engines and pump pistons are most commonly made in grey iron because of the need for resistance to wear, corrosion, and heat, and high vibration-damping capacity. Motor blocks and engine and pump cylinders require resistance to wear and corrosion and high damping capacity, together with a low cost of forming the metal to the desired shape. One of the outstanding and rather colourful examples of applying modern grey iron is in engine and compressor crankshafts. They are used in small compressors, automotive engines, and indeed, in large Diesel engines such as the submarine Diesel, where the grey-iron crankshafts weigh up to 10,000 lb. The use of grey iron in crankshafts is for the high vibration-damping capacity, a high notch-fatigue strength of the metal, good wear properties on the bearings and the low cost of forming or founding and machining to the desired shape, as compared with forging and machining. For example, a forged-steel crankshaft weighed 18,000 lb., and when ready for installation, 14,000 lb. (4,000 lb. removed). The grey-iron crankshaft for the same engine weighed 10,000 lb. as cast, and 9,200 lb. after machining.

A second group of applications involving corrosion resistance in grey iron is illustrated by paper-mill, textile and food roll driers, where resistance to corrosion against steam and frequently resistance to wear are very important. Here again the low cost of forming or founding to the desired shape is an important factor. Other examples involving more complicated designs are kettles and evaporators where the temperatures employed with grey iron are up to 650° F. In these applications, resistance to corrosion, occasionally resistance to wear, and low cost of acquiring the desired shape are afforded by modern grey iron. Indeed, in such applications the low modulus of elasticity of grey iron, of the order of one half that of steel, is taken advantage of by holding down thermal stresses. In filters of the drum type, or filter-press plates, resistance to corrosion and low cost of forming are important factors in favour of cast iron. Valves, pumps and pipe are common examples of cast-iron applications utilising the combination of resistance to wear and corrosion, and low cost of forming to the desired shape. Another common application, and one of the large outlets for grey iron, is in furnace parts. The fair level of resistance to heat of ordinary grey iron can be improved upon by the addition of alloys, usually chromium and nickel; when these are added in sufficient amounts, 22-25%, the heat resistance is of a high order.

A third group of heavy-duty uses of modern grey iron is illustrated in the following: Gears, where high-strength and high-vibration damping capacity, together with good resistance to wear, are needed; and machine-tool castings, where high vibration-damping capacity and good resistance to wear on the metal-to-metal contact in the ways make grey iron a necessity to afford the great accuracy required. Another outstanding example where advantage is taken of a combination of strength, wear resistance and improvement to resist thermal shock, is in brake drums in motor cars, including passenger cars and heavy-duty trucks, and the extreme case of grey iron brake drums for heavy-aircraft landing brakes. Metal-forming dies and rolls require a high level of strength combined with resistance to wear and vibration-damping capacity.

The examples given, in general, are peculiar to grey iron because of the presence of graphite to afford wear resistance, high vibration-damping

capacity, moderate resistance to corrosion, and equally important with these useful engineering properties are the low cost of founding, which produces parts with small machining tolerances, and ready machinability.

Limitations of Grey Iron

It is important, when discussing any particular commodity or material, that its limitations be recognised along with its advantages. Where pure tensile strength is involved such as in tie-bars, rolled steel bars are cheaper and better than any type of grey iron that might be considered. Where resistance to sudden, heavy loads is required, such as in axles of vehicles, grey iron should not be considered because of the low order of impact values of grey iron. While considering toughness, which is a qualitative term, some differentiation should be made between impacts and vibrating loads. In a crankshaft, for example, where the load is a vibrating one, the high vibration-damping capacity of graphite-containing grey iron is an advantage which has been found very useful in preventing load amplification.

When an engineer is considering design features of machinery, chemical equipment, and the like, the favourable features of grey iron to consider are metal-to-metal wear-resistance, high vibration-damping capacity, low cost of securing complicated designs, and low machining costs. The high notch-fatigue values of moderate grey iron make it an important metal to consider in competition with some of the more expensive and apparently better metals for many machine parts. Indeed, when grey iron is being considered, it is to achieve economically a combination of properties which it would be difficult to find in any other metal.

Specifying Grey Iron

In specifying grey iron, the engineer should include those properties which are vital to the part in question. For example, a strength specification alone is inadequate, since, in many cases, wear resistance, machinability, pressure tightness, modulus of elasticity or improved toughness may also be needed. With grey iron the engineer must rely on the integrity of the foundry producing his castings. This, however, is no different from the conventional practice in buying pumps, machines or other fabricated equipment.

Russian Experiments with Oxygen in Steel-Making

By V. V. Kondakov

BETWEEN October 1945, and March, 1946, experiments in steel-making, using oxygen in a Bessemer converter, were carried out at the works of the Stalin Iron and Steel Trust in Kuznetsk. Bottom blast was used through nine nozzles of 12–14 mm. dia. The converter was lined with Dinas bricks on asbestos 20 mm. thick, and its capacity was 1·52 cu. m. or 1,500 kilos pig iron Oxygen concentrations were 100%, 75% or 50%, under 80–100 atm. pressure, supplied though 3-in. pipe 450 m. in length. The converter charge consisted of Satkin converter pig and scrap steel (so proportioned that the required silicon content was maintained in melting) 12% coke and 3% flux. Suitable arrangements were provided for control of the air-oxygen mixture—in the lower concentrations—and of pressures, e.g., down to 10 atm. in the oxygen supply pipe; the usual measurements were made of temperatures and heat absorption, and samples of metal, clinker, and gases were examined at various stages. Deoxidisers used were ferro-manganese, ferro-silicon and aluminium.

It is stated that the heat generated by burning the carbon of the pig iron ("chemically cold") was sufficient to raise the temperature to 1,500° C. or more, i.e., adequate for converting into steel. Fifteen tests were made: 11 with pure oxygen, two with 75% oxygen, and two with 50%. In using pure oxygen great difficulty was experienced through the rapid wear of nozzles which only survived one test. This involved considerable delay in cooling down, renewing the bottom and nozzles, and heating up again; about two days in all. After weighing the charge of liquid pig iron and introducing blast, the first lot of deoxidiser (10 kilos ferro-manganese) was added, the metal then being poured from the converter into the ladle. A further instalment of deoxidiser was then added: 5 kilos ferro-manganese, 5 kilos ferro-silicon, and 0·7–1 kilo aluminium. The temperature of pour averaged 1,460°–1,500° C. The steel was cast into ingots, usually at one pouring, of about 1,350 kilos each. Eleven ingots were rolled into billets, round bars and strip, and subjected to detailed micro- and macro-structure analysis and the usual examination of mechanical properties.

The composition of the pig iron and steel scrap was as follows:—

Pig iron from	Si	Mn	C	S	P	Cr	Ni
Satkin	0·70	0·76	4·22	0·02	0·04	0·26	0·25
Do. ..	1·4	1·78	4·08	0·03	0·05	0·27	0·19
Steel scrap ..	0·21	0·69	0·58	0·03	0·01	—	0·06

It was decided that the silicon content of the charge should be 0·4–0·5%.

It is not clear what actual pressure of oxygen was used. Early in the report it is stated that there was a special high pressure section of the oxygen tank of 2 cu. m. capacity, and when oxygen was used the pressure was raised to 80–100 atm. A little later, pressures of oxygen of about 10 atm. are mentioned; and still later we read: "The pressure of the blast varied from 1·0–1·4 atm. and was hand-regulated according to requirements." The duration of blast with pure oxygen (0·5–1·5%N content) was 4–5 mins. with 14 mm. nozzles, and 7–7·5 mins. with 10 mm. nozzles. with reduced oxygen content, the periods were longer. The loss of metal was not greater than in ordinary Bessemer practice with normal air blast, although it seems that the percentage output of metal averaged about 80% for 100% oxygen, as compared with 90–91% for 50% or 75% oxygen content.

The total oxygen used per ton of iron was 33·4–39·6 cu. m. in the case of pure oxygen. With 75% oxygen it was 45·2 cu. m. (total air and oxygen 52·3 cu. m.); and with 50% oxygen it was 36·5 cu. m. (total mixture 45·2). This low oxygen consumption is attributed partly to the use of bottom dispersed blast, and partly to the reduced oxygen needed for the oxidation of "chemically cold" pig iron compared with ordinary Bessemer charges with 1·5–2% Si.

Various tables show the chemical composition and mechanical properties of the grades of steel produced. Among the general conclusions, it is pointed out that further tests should be made in respect to removal of phosphorus and that one of the chief outstanding problems is that of a more resistant nozzle material and possibly also improved design and disposition of nozzles. Further study is also required of automatic control, e.g., for determining completion of the melt according to the kind of steel desired.

From *Bull. Acad. Sci.*, U.S.S.R., 1946, No. 10, (Tech. Sect.)

Dissimilar Metals Joined by Step Brazing Methods

By I. S. Goodman

IN the manufacture of the Magnetron type of electronic tube, all but one of the 18 metal-to-metal joints are brazed, and 15 of them must be vacuum-tight. The metals concerned are molybdenum, tungsten, Monel metal, stainless steel, Kovar, OFHC copper and selenium copper. As the glass envelope is applied after the brazing, in general, and as the tube itself is treated at over 750° F., this temperature sets a lower limit on the brazing alloy melting points, the higher limit being set by the parts themselves.

Since zinc, cadmium, lead, and similar metals have sufficiently high vapour pressures at 750° F. to deposit themselves in undesirable locations and to degrade the vacuum, such metals cannot be part of the brazing alloys. this, therefore, limits the metals that can be used for brazing to copper, silver, nickel, gold, platinum, tin, indium, and their alloys.

A further limitation is that many of the suitable brazing metals just mentioned form eutectic systems. This means, for example, that two copper parts joined by a 50 silver, 50% copper brazing alloy cannot subsequently be brazed to another part with another copper-silver alloy within the eutectic range. For this would result in remelting the eutectic portion of the first braze with a possible shift of the parts. Nor can any other alloy of any composition of higher melting point be used for the same reason.

Other restrictions arise from the metals themselves. Tungsten is poorly wet by silver alloys. The use of silver alloys on Kovar (widely used in glass tubes because its coefficient of expansion matches glass) sometimes leads to stress-corrosion cracking similar to that experienced on steel. Finally, tolerances on many of the parts are ±0·003 in. and occasionally ±0·001 in., and concentricity tolerances on brazed parts are frequently ±0·005 in. or better.

All the brazing on these tubes is performed in a hydrogen atmosphere to avoid the difficulties associated with flux removal. The brazing can be done in a conventional pusher-type or continuous belt furnace or in a hydrogen bottle. In the latter the hydrogen goes in through the closed top and out of the open bottom. Heat is supplied by a tungsten coil heated to 3,630° F. or even higher. By this means the heat may be localised at the joint and so minimise the risk of softening the joint at the other end of a component.

In the assembly of the Magnetron tubes, there are eight separate brazing operations. In order that each joint, once completed, shall not be melted in subsequent operations, the technique of step brazing is used. Briefly, this involves arranging the sequence of operations in such a way that successively lower melting point brazing alloys are used.

Although step brazing methods such as just described have at present met the problem of joining dissimilar metals without affecting previously brazed joints, it can be seen that the way is open for newer and potentially cheaper alloys and techniques to match the advanced design changes in electronic equipment and other products where similar problems arise.

As germanium and indium become less expensive and more developed, metallurgically, the number of alloys available to the metal-joining engineer will increase. But at present those alloys with low vapour pressures, mentioned in the early part of this article, are the only ones available. Of these, copper is by far the most common both because it makes excellent joints between ferrous components and because of its low cost.

The most commonly used system is that of silver-copper. These alloys are free-flowing and fillet nicely, particularly on non-ferrous alloys. However, they must be used with caution on ferrous parts under stress because of the phenomenon of stress-corrosion cracking. Also, these alloys are a eutectic system and, accordingly, some or all of the alloy will melt at 1,435° F. between the limits of 9 copper, 91% silver, and 8 silver, 92% copper.

Among the alloys used for brazing by the electronics industry, those containing gold have been used with success. These alloys—those of the gold-silver, gold-copper, and gold-silver-copper systems—have the advantage of flow points between those of silver-copper alloys and copper. They also flow well and wet both ferrous and non-ferrous surfaces. One weakness is the occurrence of age-hardening alloys in the range of 40 to 90% gold in the gold-copper system. Some of the alloys that have been used successfully are: 75 gold, 20 copper, 5% silver (1,632° F. melt, 1,654° F. flow); 58 gold, 40 copper, 2% silver (1,670° F. melt, 1,715° F. flow); 42 gold, 55 copper, 3% silver (1,720°F melt, 1,760°F flow); and 30 gold, 70% copper (1,796° F. melt, 1,850° F. flow).

Since copper does not alloy with molybdenum and tungsten, it is found advantageous to add nickel to brazing alloys for use on such parts. Since copper and nickel form a simple series with complete miscibility in both the liquid and solid states, 10 to 30% nickel-copper alloys have been used with excellent results. Where higher operating temperatures are required, pure nickel (2,650° F.) has been used. Such joints will not have high tensile strengths, however, due to the formation of brittle nickel refractory eutectics. Where both high-temperature and high-tensile are required, platinum (3,223° F.) has replaced nickel.

Where low melting points are permissible and the parts are copper, alloys containing copper-phosphorus eutectics may be used. The most common are 7 phosphorus, 93% copper (1,305° F. melt, 1,382° F. flow) and 5 phosphorus, 80 copper, 15% silver (1,186° F. melt, 1,300° F. flow). Neither alloy is recommended on ferrous alloys due to phosphiding effects with iron.

Although a gold-indium alloy with an operating temperature about 1,110° F. has been developed and used, there is no inexpensive, ductile brazing alloy in the field of 750° F. to 1,300° F. that may be safely used on vacuum devices operating up to 750° F. Yet such an alloy would enjoy considerable demand. Electronic design engineers would frequently like to braze after glassing. Since the softening point of glass is about 1,100°F., this sets an upper limit upon the brazing alloy whose lower limit (750° F.) is set by the operating temperature of the device.

Thus far little has been said about welding other than its use in joining a Monel stud to a Monel diaphragm. Welding is a potential way out of the complexities of step brazing since welds can be made on semi-finished assemblies without temperature effects on previous joints. Too little is known, however, concerning the technology of welding dissimilar metals to obtain dependable joints of large diameter which will be consistently vacuum tight. This is particularly true for combinations of ferrous and non-ferrous metals such as copper to steel or Monel

From *Materials and Methods*, August, 1948, **28**, 2, pp. 64-67.

to aluminium. Even with similar metals, a vacuum-tight weld of 1½ in. in dia. in mild steel requires over 300 kVa, single-phase welding capacity and a 2-in. dia. weld over 500 kVa. Nonethe-less, experiments are under way in resistance welding, arc welding, and induction welding to accomplish heretofore " impossible " welds, and joining dissimilar materials is still a challenge to both the designer and metallurgist to co-operate to the end of producing better and more efficient products.

Arc Welding Red Brass

By Louis P. Benua

WELDING red brass is complicated by vapourisation and oxidation of certain elements, chiefly zinc, which causes weld porosity. Material specifications of the tank and cooling coil assembly on an electric drinking-water cooler made by Ebco Mfg. Co., were recently changed to 85-15 red brass (85% copper, 15% zinc). The change in material immediately presented a problem in welding the heads onto the deep drawn tanks.

An automatic carbon arc welder was available in the plant and, because it had been successfully used in welding the heads on galvanized steel cans it was decided that the unit could be adapted to welding the red brass tanks. Since there is little available published information and apparently little experience with the carbon arc welding of red brass, it was necessary to start at the beginning and develop procedures.

When production was first started with the automatic carbon arc process using a flux, considerable difficulty was experienced because of pin holes in the welds. By using a baffle in the tank as a backing strip for the weld and changing the flux to a home-made mixture of two commercial brands, rejections were eventually cut down to the point where the manufacture of these tanks became economical.

The process, however, was not completely satisfactory and inert gas shielded arc welding was tried. With a few changes, the Lincoln Tornado automatic carbon arc unit was adapted for use with helium gas.

An austenitic stainless steel water-cooled nozzle was made to fit the boot of the Tornado welder through which both the gas and the carbon electrode is directed onto the work. It was necessary to use austenitic stainless steel since the purpose of the Tornado boot is to create an electro-magnetic field which is used to stabilize the arc. The non-magnetic properties of the stainless permitted its use without disturbing the functions of the boot.

In welding the head to the tank by the inert gas shielded arc method the 85-15 red brass tank is placed in a special lathe where the refrigerant tubing is wrapped around it. The tank and coil then are hot tinned by dipping and are ready for welding.

The head for the tank, which is also hot tinned, is clamped to the tank in a power driven welding fixture so that the flanges come directly under the carbon electrode. The fixture rotates the assembly under the welding head as the weld is made. The arc is struck at a reduced amperage and the cooling tank is started rotating at a speed of approximately 15 in/m. In order to compensate for the heat that builds up in this light tank, the speed of rotation is gradually increased during the welding cycle. In this way a uniform weld with good penetration is obtained.

The inert gas is consumed at the rate of 4·2 cu. ft. per min. A solenoid valve, operated by a cam on the driving mechanism of the fixture, controls the flow of gas delivered by the nozzle. The nozzle is close to the work to provide the protective gas envelope. The carbon electrodes are $\frac{5}{16}$ in. diam. and welding is carried out at 150 amp. using from 18 to 20 v.

Welding with inert gas and the carbon arc, according to the procedures outlined, has produced highly satisfactory results. Because of the deeper penetration obtained and the stronger welds made, the bursting strength of the tanks has been raised from 500 to 1,000 per sq. in. Furthermore, the tin coating readily melts and flows down over the bead. Relatively inexpensive carbon electrodes are used and they last ten times as long as when the job was done with flux.

From *Iron Age*, June 17th, 1948, pp. 77-79.

Stabilisation of Austenitic Stainless Steel

A RECENT investigation by Rosenberg and Darr* on the effect of variation in carbon content, in the Cb : C and Ti : C ratios and in heat-treatment, on the intergranular embrittlement or corrosion of austenitic stainless steels has produced some interesting results. The steels used were mostly experimental melts prepared to a specification of 18% chromium, 10% nickel, 1·25% manganese and 0·4% silicon.

As part of the investigation a variety of test conditions, some of them quite severe, were used to study susceptibility to intergranular attack. Specimens were sensitised at temperatures ranging from 840° to 1,380° F. for periods up to 21 days, followed by exposure to the boiling acidified copper sulphate solution for 14 days. It was found that the most severe sensitising treatment was 8 or 21 days at 1,020° F. Compared with this, the commonly specified treatment of 2 hr. at 1,200° F. is relatively mild.

Considering the steels which contained no stabilising elements, the tests showed that all were vulnerable to intergranular attack. Decrease in carbon content, however, decreased the degree of vulnerability.

In the columbium- and titanium-bearing steels, carbon content within the range of 0·06 to 0·13% had no influence upon the resistance to intergranular attack except as it influenced the Cb : C or Ti : C ratios. Steels varying in carbon content but having similar ratios of Cb : C or of Ti : C had approximately the same degree of susceptibility to intergranular attack regardless of the total carbon content. The steels showed greater resistance to attack when annealed at 1,800° F. than when annealed at 1,975° F.

Stabilizing heat-treatments at 1,600° F. had a negligible effect upon the resistance to intergranular embrittlement of the columbium-treated steels so that those steels carrying a sufficiently right ratio of Cb : C may be used without giving them a stabilising heat-treatment. However, the performance of the titanium-treated steels carrying the higher ratios of Ti : C. was markedly improved by such treatments. When properly treated, substantially complete immunity to intergranular attack may be obtained with a minimum ratio of Cb : C = 10 and Ti : C = 5. For more complete immunity, these ratios should be 12 and 8, respectively.

The type of distribution of the precipitated carbides resulting from the sensitising treatment was not an infallible indication of the resistance to intergranular embrittlement. Steels in which the carbides were distributed

Continued on Advertisement page 62

From *Iron Age*, June 17th, 1948, p. 8.
* *J. Res. Nat. Bur. Stand.* R.P. 1878. April, 1948.

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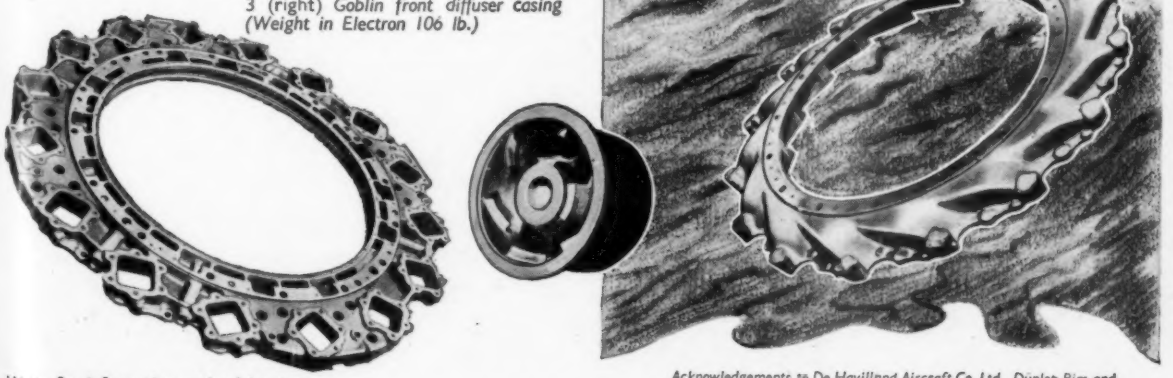
2 (centre) *Vampire wheel hub (Weight in Elektron 26 lb.)*

3 (right) *Goblin front diffuser casing (Weight in Electron 106 lb.)*



Acknowledgements to De Havilland Aircraft Co. Ltd., Dunlop Rim and Wheel Co. Ltd. Castings in Elektron by Sterling Metals Ltd., Nuneaton

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at random were usually resistant to intergranular attack. However, steels that contained carbides at the grain boundaries, even though these carbides were distributed as a continuous network, either were or were not susceptible to intergranular attack, depending on the time-temperature relationship during sensitisation. For example, two specimens of a straight carbon (0·09%) austenitic steel, one sensitised 2 hr. at 1,200° F. and the other 2 days at the same temperature, were indistinguishable on examination of their microstructure. Both showed a precipitation of carbides at the grain boundaries and on various slip planes. Their behaviour after exposure to the boiling acidified copper sulphate, however, differed radically. The specimen that had been sensitised 2 hr. suffered severe intergranular corrosion after 2 days' exposure, while that sensitized for 2 days showed no evidence whatever of intergranular attack even after 14 days.

Fatigue Tests of Spot Welds

Improvement of Their Endurance Limit by Hydrostatic Pressure

By G. Welter

SPOT-WELDED Alclad 24ST aluminium alloy specimens, also stainless steel and mild steel specimens, have been investigated with regard to their metallographical and mechanical properties in the "as-received" condition as well as after special treatment of the spots under high hydrostatic pressure. On basis of radiographs of each weld mostly sound specimens could be selected for investigation under fatigue tests ranging from O to maximum tension loads. These tests revealed that an appreciable increase of the endurance limit of spot-welded alloys is possible if, after welding, the spots are treated by being placed under high hydrostatic pressure; this pressure was gradually increased to 230,000 per sq. in. At 10,000,000 cycles an improvement of 250 to 300% of the fatigue resistance of 24-ST alloy specimens seems quite possible.

From *Welding Journal*, **27**, No. 6, pp. 285-s—298-s, June, 1948.

Abstracted in *Light Metals Research*, **9**, 17.

Cathodic Protection of Steel in Sea Water with Magnesium Anodes

By R. A. HUMBLE.

THE object of the research work reported was to select the magnesium alloy most suitable for cathodic protection with respect to solution potential, freedom from polarisation and current efficiency. Experiments carried out included tests on the anodic performance of magnesium in sea-water and determinations of the current requirements for the cathodic protection of steel. It was found that magnesium anodes gave protection with current densities as low as 3 m.a./sq. ft. following the application of a high initial current density (50 m.a./sq. ft.) to achieve immediate polarisation. The high initial current density stabilises the current requirements with respect to time and permits the use of smaller permanent anode installations.

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